# STUDIES ON MODELLING APPROACHES IN SOLID WASTE MANAGEMENT

SYNOPSIS OF THE

THESIS

SUBMITTED FOR THE AWARD OF THE DEGREE OF

**Doctor of Philosophy**

IN

CIVIL ENGINEERING

BY

**SHEEBA KHAN**

Under the Supervision of

**Dr. I.H. FAROOQI**

DEPARTMENT OF CIVIL ENGINEERING
Z.H. COLLEGE OF ENGINEERING AND TECHNOLOGY
ALIGARH MUSLIM UNIVERSITY
ALIGARH (INDIA)

2010

Synopsis of the Thesis

# STUDIES ON MODELLING APPROACHES IN SOLID WASTE MANAGEMENT

Submitted for the award of the degree of

Doctor of Philosophy

By

**Sheeba Khan**

Under the Supervision of

Dr. I. H. Farooqi

DEPARTMENT OF CIVIL ENGINEERING
ALIGARH MUSLIM UNIVERSITY
ALIGARH (INDIA)
SEPTEMBER 2010

# STUDIES ON MODELLING APPROACHES IN SOLID WASTE MANAGEMENT

## SYNOPSIS

### 1. INTORDUCTION

Every human activity creates waste (Tchobanoglous et al., 1993). India is the second most populous nation in the world; the uncontrolled growth of urban areas has led to deficiency in infrastructural services such as: water supply, sewage and municipal solid waste management (MSWM). The burgeoning population has resulted in a massive pressure on the health-care services, leading to huge amounts of hospital/ infectious waste generation. The urban population is estimated to be 285 million, which is concentrated in a few large cities and 32 metropolitan cities. It account for 34.5 percent of the urban population and is expected to reach 341 million by 2010 (Census of India, 2001). The number of Class I cities with population exceeding 1, 00,000 has increased from 212 to 300 during 1981 to 1991 (CPHEEO, 2000). It is interesting to note that as much as 65.2% of the urban population is living in these Class I cities. The growth in generation of municipal solid waste (MSW), in recent years, has been exponential due to the booming Indian economy. There has been increased change in the standard of living in the urban areas of the country, which has left the civic authorities in a tight spot. The waste quantities are estimated to increase from 46 million tones in 2001 to 65 million tones in 2010 (Kumar and Gaikwad, 2004). Most urban areas in the country are suffering from lack of solid waste management (SWM) problems, despite the fact that large sums of municipal expenditure is earmarked for it.

Most of the municipal corporations of the country under who the purview SWM of cities lie are unable to meet the national and international standards owing to non-availability of adequate expertise and experience; resulting in improper handling of solid wastes, which further leads to environmental degradation and health hazards. Moreover, the municipal solid waste management (MSWM) is under taken by the civic agencies that are fund starved. Therefore, use of appropriate and effective resources such as technology, equipments and human resources becomes difficult, which leads to wide-spread public discontent. MSWM issues have moved to the fore of the public agenda, with levels of concern and activity by citizens and governments world-wide reaching unprecedented levels (Read et al., 1997). The lack of funds makes it crucial for the civic authorities to perform in the best capacity and to avoid any failures in the strategies and in important selections. With the stellar growth in the Indian economy, the amount of generated waste is rising, resulting in overburdened labor and an increase in the cost of operation of MSWM. Therefore, it is imperative that effective and appropriate programs should be investigated for the improvement of a solid waste management system in the urban areas of the developing countries (Tin et al., 1995).

Health-care waste, apart from the municipal waste, that needs urgent attention in developing countries such as India. The most authentic definition from the WHO characterizes health-care waste (HCW) as those wastes generated from hospitals, medical centers, health-care establishments and research facilities in diagnosis, treatment, immunization and associated research (Ananth et al., 2010). A hospital is a center that provides various health-care services to the community. Its activities may include curative, rehabilitation, preventive and promotion of health education. In undertaking the activities, the hospital may also generate wastes both from medical and non-medical activities. The infectious components in the hospital wastes could pose a potential risk to the patients, neighboring communities, hospital staff (especially waste workers), visitors and even the surrounding environment. This area of waste management is grossly neglected. Infectious and non-infectious wastes are not segregated at the source and are taken to incineration plant in unhygienic manner. The system adopted for the collection, transportation, and disposal of hospital waste lacks scientific and efficient design.

## 2. RESEARCH ISSUES IN SOLID WASTE MANAGEMENT

According to MoEF (2010), the Ministry of Urban Development (MoUD) assessed MSW generation in the country to be 1, 00,000 metric tons or 0.1 million metric tones per day (MMT/d) in the year 2001-02. The Central Pollution Control Board (CPCB) made a survey of 59 cities in India during the year 2004-05 to assess the existing status of MSW management which included 35 metro cities and 24 state capitals. Based on this study and on census data of 2008, the MSW generation in the country has been estimated to be 0.573

MMT/d in the year 2008. This staggering amount of the waste generated in India warrants that effective management tools should be adopted in order to solve the conundrum of the SWM. Moreover, the World Bank (1999) states that the problem of SWM is beyond the ability of the municipal governments and they need assistance from the other levels of government, businesses and the general community to combat the problem of mismanagement of solid waste. It mentions that parts of India may face greatest waste management challenge in addition to other Asian countries; such as Indonesia, Philippines, and parts of China.

SWM, of ay kind, is an amalgamation of plethora of issues such as political, economical, social, technical and environmental. Since it is a multi-faceted crisis, the answer to this problem is multi-criteria decision making (MCDM). People involved in the management of solid waste find it difficult to arrive upon an optimum solution to a particular problem, as it becomes difficult to satisfy all the constraints. MCDM is a technique that enables to arrive upon a most pragmatic selection or solution by considering all the factors, which may be of conflicting criteria and uncertainty. The major issues plaguing the municipal SWM are:

- lack of appropriate priority among the different issues in planning a scheme,
- selection of appropriate disposal scheme,
- lack of identification of the real issues and the interaction among them, which may assist or inhibit any SWM plan,
- limited involvement of the public in SWM plans.

Being the second most populous country in the world, India is in dire need of not only improving its health-care, but also its health-care waste. It becomes all the more important as India is emerging as a global destination for a cheap, yet quality health-care hub. The major issues in the hospital waste management (HWM) are:

- lack of schematic and logical criteria in selection of hospital waste handlers,
- inappropriate selection of HW managing person,

- lack of identification of adequate HW management issues and the interaction among them.

## 3. IDENTIFIED GAPS IN LITERATURE

- For effective MSWM the various factors that are taken in consideration while formulating a scheme should be identified correctly and should be given due importance for the plan to be a success. Otherwise, the most inventive schemes also turn useless. The primary measure of success of a designed scheme is the degree to which it meets the purpose for which it is intended (Khan et al., 2008). People satisfaction is commonly acknowledged as one of the useful proxy measures of MSWM success. Hence, it is essential to identify MSWM factors for setting satisfactory system standards.

- Inappropriate disposal of MSW, especially in developing countries, poses severe environmental and health threats. Environmental degradation such as underground water pollution, surface water pollution, air pollution and soil pollution occurs. Health impacts such as increase in the incidences of the diseases, impaired health due to increased exposure to pathogens, breathing problems and death may occur. Selecting appropriate plan for the disposal of the waste, by taking into account all the different issues and factors is a tedious task. This kind of decision-making environment involves an ill-defined problem in which behavioral decision research shows that humans are typically quite ineffective at solving, problems involving SWM unaided ( Promentilla et al., 2006).

- Huge disparity exists between MSWM researches in developed countries versus developing countries. Studies in the developed countries focus primarily on technical applications such as models and tools, policy analysis, socio-psychological, socio-economic influences on human behavior. However, research on MSWM in the developing world places more emphasis on the practical, direct factors influencing the institutions and elements associated with MSWM. Not much work has been done in understanding the indirect motives of one's behavior (i.e., recycling research focus in developed countries), though a couple of studies (such as Corral-Verdugo, 1997, 2003; Li, 2003) have been performed that seem to be on the lines and issues similar to that in the developed nations.

- Globally, in 1985, 41% of the world population lived in urban areas, and by 2015 the proportion is projected to rise to 60 % (Schertenleib, 1992). Of this urban population 68 % will be living in the cities of low-income and lower middle-income countries. Since consumption is unstoppable and ever increasing, waste production is becoming gradually more important and its disposal is a problem that seriously threatens the sustainable development of society today (Benítez et al., 2008). Thus, there is an urgent need to study exhaustively the variables that encourage effective MSWM, so that the world-wide menace of augmenting MSW could be tackled in order to diminish the environmental and health hazards.

- Government of India has framed Bio-Medical Waste (Management and Handling) Rules1998 making it mandatory for health-care facilities (HCFs) to properly dispose bio-medical waste. However, the institutions do not comply with the rules and the conditions within them are pathetic. Therefore, there is urgent need to improve upon the medical waste management practice. Hence, systematic and planned approach to deal with the infectious or bio-medical waste is required to guide the hospital management in particular towards better medical waste management practice.

- Some of the major health-care facilities (HCFs) in India are treating the infectious waste by on-site incinerators or steam sterilization facilities at some general hospitals, where incinerators or steam sterilization is available, small and medium HCFs may not be in a position to install required equipment on their premises. It may, therefore, be appropriate for small HCFs to outsource waste management, handling and disposal. Ruoyan et al. (2010) observed regarding the small or the primary health-centers in handling infectious waste that off-site treatment for the small and medium HCFs is important not only because of economic considerations, but also for the environmental implications. It is noted that off-site disposal allows the local environmental authority to monitor management system and handling the local environmental authority to monitor management system and handling procedures effectively. Thus, making the selection of appropriate infectious waste handling contractors an onerous task for the medium and small and medium HCFs due to the number of safeguards.

- Developing economies, such as India, have seen rapid industrial and economic advancements and urban growth coupled with manifold increase in population in the last two decades. These trends have also put health-care facilities under severe stress to meet the growing demand, leading to an increase in health-care waste generation. The waste generated from hospitals is now viewed as a serious health hazard in many countries (Gupta and Boojh, 2006). In many countries, hazardous and medical wastes are still handled and disposed together with domestic wastes, thus creating a great health risk to municipal workers, the public and the environment (Da Silva et al., 2005). Improper disposal of wastes in hospitals places direct and indirect health impacts on those working in hospitals and the surrounding communities, and on the environment (Akhter and Trankler, 2003). Safe management and disposal of these wastes is an essential component in the maintenance of adequate hygiene standards, safe working conditions and effective risk reduction (Blenkharn, 2008).

## 4. OBJECTIVES OF THE RESEARCH

The objective of this thesis is to use the available MCDM techniques in order to assist people involved in managing the solid wastes. This thesis is divided in two parts: first MCDM techniques have been applied to municipal solid wastes (MSW) and second, the same techniques have been applied to hospital waste scenario. The major objectives of the thesis are:

- To understand that SWM is part of broader urbanization problem,
- To understand the attitude and psyche of the people, for making MSWM successful,
- To develop a framework to model and prioritize the different factors of (a) MSWM plan, and (b) infectious waste management,

- To develop a framework for the selection of the best alternative available to formulate a solid waste plan,
- To develop a framework to understand the relationship among the various enablers and barriers of MSW and hospital waste.

## 5. RESEARCH MEHEDOLOGY

1. *Fuzzy Analytic Hierarchy Process (Fuzzy-AHP):* AHP is a decision-making methodology used to solve multi-criteria decision problems. This method has been used in fuzzy form to prioritize factors for modeling of MSWM and for prioritizing factors for selection of infectious waste management contractors as well.

2. *Analytic Network Process (ANP):* ANP is used as a tool to solve multi-criteria decision making problems. In this research ANP is used to select the best alternative to disposal options in MSWM and select the best infectious waste firm for the handling of the hospital waste. It provides opportunity to the researcher to simultaneously consider the impact of criterion, sub-criterion and their interrelationships to select the best alternative under consideration.

3. *Questionnaire based survey:* This is used to gain a broad insight into the public psychology towards MSWM per se, waste generation habits and problem areas of SWM Indian cities. A questionnaire based study was conducted in the areas, where Japanese International Cooperation Agency (JICA) funded pilot project for the segregation of MSW was undertaken by MCD in 2004. The study was then compared with the similar survey based in another Asian city Doha, capital of the state of Qatar.

4. *Interpretive Structural Modeling(ISM):* It is used for analyzing different interactions among different barriers in MSWM and HWM. It is also employed to find the key variables, which are of strategic nature and management is required to carefully focus on them to improve other dependent variables of the system.

## 6. SIGNIFICANT RESEARCH CONTRIBUTIONS

- The focus in SWM studies is on the various emerging and new technologies being used to dispose the solid waste, but there exists a gap in studying the psyche of the people, who are involved and hold the key to any success for the management of such schemes.

- Participation of people increases due to environmental concern and the easily accessible infrastructure of such as curbside recycling.

- Women seemed to take a lead in the programs aimed for management of solid wastes in any given area.

- In the study it was found out that there exists a significant difference among the people of different age groups regarding their involvement in the SWM plans.

- Though feedback about the state of the management of the solid waste has emerged as a major element of any SWM scheme being implemented, the executioners and the formulators remain non-committal about disseminating the results of the scheme.

- The percentage of population involved in recycling and composting plays a more important role in the formulation of scheme for MSWM than the population served through the implemented scheme.

- Incineration as a disposal method for the MSW was rejected primarily due to utilizing incineration warrants installing expensive environmental control systems. Moreover, the composition of the municipal waste generated in the Indian cities is not suitable for the combustion purposes.

- Segregation of the MSW is the key to effective and efficient MSWM. Therefore, public participation is must to combat the problem of municipal solid waste.

- Several constraints such as cost, waste characteristics and the social practices and inhibitions exists that makes difficult for the civic agencies to adopt the state-of- the-art technologies for SWM that are being used in the developed countries all over the world.

- A combination of techniques (such as landfilling and composting) is the best approach for the disposal of MSW in India. Incineration is the least preferred disposal option for MSW not only because of the heavy investment involved in the installation of air pollution control devices, but because the characteristics and composition of the municipal waste are unsuitable for incineration.

- Redress and appeal system and conforming environmental regulations are the two most important criteria in selection of the infectious waste contractors.

- From the study it was found that, when selecting the infectious waste contractor hospitals gave more weightage to the contractor's qualification followed by contractor's service capability. This entails that the health-care organizations are quite concerned about the environmental regulations and are determined to innocuously dispose the infectious waste generated.

- Ambiguous policies exist in the bio-medical or infectious waste management; lack of appropriate guidelines and lack of awareness about potential risks there is no strategic commitment by top management leading to financial constraints impacting the training of personnel involved in handling of the infectious waste.

- Lack of co-operation and co-ordination among various agencies involved in the infectious or the bio-medical waste management exists, which results lack of enforcement mechanism, modern disposal methods and off-site transport facilities.

## 7. ORGANIZATION OF THE THESIS

The following figure depicts the organization of the thesis.

| | |
|---|---|
| **Chapter 1** | INTRODUCTION |
| **Chapter 2** | LITERATURE REVIEW: Study of the published research work in the modeling of SWM |
| **Chapter 3** | PRIORITIZING SOLID WASTE MANAGEMENT FACTORS USING FUZZY ANALYTIC HIERARCHY PROCESS: Prioritization of MSWM factors and HWM factors using Fuzzy-AHP |
| **Chapter 4** | ANALYTIC NETWORK PROCESS MODEL FOR SELECTION OF ALTERNATIVES: Selection of best alternative for disposal of MSW and infectious waste contractor using ANP |
| **Chapter 5** | EVALUATING PEOPLES ATTITUDES AND PARTICIPATION IN MUNICIPAL SOLID WASTE MANAGEMENT: A COMPARATIVE STUDY IN INDIA AND QATAR: Questionnaire study and hypothesis testing from data collected in Delhi and Doha |
| **Chapter 6** | INTERPRETIVE STRUCTURE MODEL FOR ANALYSIS OF ENABLERS AND BARRIERS IN SOLID WASTE MANAGEMENT: Understanding the interactions, using ISM, among the various enablers / barriers for the effective MSWM and HWM |
| **Chapter 7** | SUMMARY, LIMITATIONS AND SCOPE FOR FUTURE WORK: Conclusions, scope and limitations to the research work are presented |

**Figure 1.1: Chapter organization of the thesis**

*Key References*


1. Aragonés-Beltrán, P., Pastor-Ferrando, J. P., García-García, F., and Pascual-Agulló, A. (2010) 'An analytic network process approach for siting a municipal solid waste plant in the metropolitan area of Valencia (Spain)', *Journal of Environmental Management* Vol. 91, pp. 1071–1086
2. Blenkharn, J.I. (2008) 'Standards of clinical waste management in hospitals-A second look', *Public Health*, Vol. 121, pp. 540-545
3. Census of India (2001) http://www.censusindia.gov.in/default.aspx (Last Accessed June 14, 2010)
4. CPCB (1999) '*Status of solid waste generation, collection, treatment and disposal in metro cities*', Central Pollution Control Board, Delhi.
5. CPCB (Central Pollution Control Board) (2000) '*Management of Municipal Solid Waste Delhi*', Central Pollution Control Board
6. CPHEEO (2000) '*Manual on municipal solid waste management*', Central Public Health and Environmental Engineering Organization, Ministry of Urban Development, New Delhi.
7. Corral-Verdugo, V. (2003) 'Situational and personal determinants of waste control practices in northern Mexico: a study of reuse and recycling behaviors', *Resources, Conservation and Recycling* Vol. 39, pp. 265-281
8. Daskalopoulos, E., Badr, O. and Probert, S. D. (1997) 'Economic and environmental evaluations of waste treatment and disposal technologies for municipal solid waste', *Applied Energy*, Vol. 58, No. 4, pp.209-255
9. Delhi Pollution Control Committee < http://dpcc.delhigovt.nic.in/act_bmw.htm> Last accessed August 25, 2008
10. De Young R. (1991) 'Some psychological aspects of living lightly: desired lifestyle patterns and conservation behavior', *Journal of Environmental Systems*, Vol. 20, pp. 215-27
11. Diaz, L.F., Savage, G.M. and Eggerth, L.L. (2005) 'Alternatives for the treatment and disposal of healthcare wastes in developing countries', *Waste Management*, Vol.25, pp. 626–637
12. Ebreo, A. and Vining, J. (2000) 'Motives as predictors of the public's attitudes toward solid waste issues', Environmental Management, Vol. 25, No. 2, pp. 153–168
13. Emery, A., Davies, A., Griffiths, A. and Williams, K. (2007) 'Environmental and economic modelling: a case study of municipal solid waste management scenarios in Wales', Resources Conservation and Recycling, Vol. 4, No.3, pp. 244–263
14. Gottinger, W.H. (1988) 'Theory and methodology: a computational model for solid waste management with application', *European Journal of Operational Research*, Vol. 35, pp. 350–364
15. Gupta, S. and Boojh, R. (2006) 'Report: Biomedical waste management practices at Balrampur Hospital, Lucknow, India', *Waste Management & Research*, Vol. 24, pp. 584-591
16. Hokkanen, J. and Salminem, P. (1997) 'Choosing a solid waste management system using multicriteria decision analysis', *European Journal of Operational Research* Vol. 98, pp. 19–36
17. Kumar, S., Gaikwad, S.A., Sehkdar, A.V., Kshirsagar P.S. and Singh, R.N. (2004) 'Estimation method of national methane emission from solid waste landfills', *Atmospheric Environment*, Vol. 38, pp. 3481–7

18. MCD (2005). Municipal Corporation of Delhi. 'A report on the solid waste management in Delhi', National Workshop on Municipal Solid Waste Management: Sharing of Experiences and Lessons Learnt, New Delhi
19. Morrissey, A.J. and Browne, J. (2004) 'Waste management models and their application to sustainable waste management', *Waste Management* Vol. 24, pp. 297–308
20. Notification: Bio-medical Waste (Management and Handling) Rules, (1998) Ministry of Environment and Forests, GOI (E), part 3(ii), New Delhi
21. Patil, G.V. and Pokhrel, K. (2005) 'Biomedical solid waste management in an Indian hospital: a case study', *Waste Management*, Vol. 25, pp. 592-599
22. Petts, J. (2000) 'Municipal waste management: inequities and the role of deliberation', *Risk Analysis* Vol. 20, No. 6, pp. 821–832
23. Read, A. D., Phillips, P. and Robinson, G. (1997) 'Landfill as a future management option on England: the view of landfill operators', *Resource, Conservation and Recycling*, Vol. 20, pp. 183-205.
24. Refsgaard, K. and Magnussen, K. (2009) 'Household behaviour and attitudes with respect to recycling food waste experiences from focus groups', *Journal of Environmental Management* 90 760-771
25. Shekdar, A.V. (2009) Sustainable solid waste management: An integrated approach for Asian countries *Waste Management*, Vol. 29, No. 4, pp. 1438-1448
26. Siru, D., Pillay, M.S. and Sinha, K. (2006) 'A national approach to clinical waste management', *Journal of Solid Waste Technology and Management* Vol. 32, No. 4, pp.199-205
27. Tchobanoglous, G., Theisen, H., and Vigil, S.A., (1993). '*Integrated Solid Waste Management Engineering Principles and Management Issues*', McGraw Hill, New York
28. United Nations 2008 http://www.un.org/esa/population/ (Last accessed 5th June 2010)
29. UNDP (2005). United Nations Development Program. Human Development Report. Obtained through the internet http://hdr.undp.org/en/reports/ (Last accessed 25th May 2010)
30. United States Environment Protection Agency (USEPA) (2002) http://www.epa.gov/ (Last accessed 20th June 2010)
31. Verma, L. K., Mani, S., Sinha, N. and Rana, S. (2008) 'Biomedical waste management in nursing homes and smaller hospitals in Delhi', *Waste Management*, Vol. 28, No. 12, pp. 2723-2734
32. Vining, J. and Ebreo, A. (1990) 'What makes a recycler? A comparison of recyclers and non-recyclers', *Environment and Behavior*, Vol. 22, pp.55-73
33. World Bank (1999) 'What a waste: solid waste management in Asia', http://web.mit.edu/urbanupgrading/urbanenvironment/resources/references/pdfs/WhatAWasteAsia.pdf (Last accessed 24th June, 2010).
34. WHO (1999). World Health Organization. 'Safe management of wastes from health-care activities', In: Prues, A., Giroult, E., Rushbrook, P. (Eds.), World Health Organization, Geneva.
35. WHO (2007). World Health Organization. 'Wastes from Health-care Activities, WHO information, Fact Sheet No. 253', WHO, Geneva, available at: http://www.who.int/mediacentre/factsheets/fs253/en/index.html (25th June 2010)
36. World Bank (2008) http://data.worldbank.org/about/country-classifications (Last accessed on 28th June 2010)

## Papers published/accepted/communicated from this research

### Papers published/accepted in Journals

1. 'Analysis of interactions among the barriers to effective hospital waste management', *International Journal of Behavioural and Healthcare Research*, Vol. X, No. Y.
2. 'Prioritizing Municipal Solid Waste Management Factors in India using Fuzzy Analytic Hierarchy Process' *International Journal of Environment and Waste Management*, Vol. X, No. Y.
3. An analytic process model for selection of infectious waste management contractors', *International Journal of Mathematics in Operational Research,* Vol. X, No. Y.
4. 'An analytic network process model for municipal solid waste disposal options', (2008), *Waste Management*, Vol. 28, pp. 1500–1508

### Papers presented/published in Conferences

1. 'Analysis of interactions among the barriers to effective hospital waste management in India', (2008) The 23rd International Conference on Solid Waste Management, Philadelphia, USA
2. 'Some Major Issues in Municipal Solid Waste Management: A Review', (2010) International Conference on Emerging Technologies for Sustainable Environment, Aligarh, India
3. 'Biomedical Waste Management: Issues and Challenges', (2010) International Conference on Emerging Technologies for Sustainable Environment, Aligarh, India

### Papers communicated

1. 'Evaluating peoples attitudes and participation in municipal solid waste management: a comparative study in India and Qatar', The 26th International Conference on Solid Waste Management, Philadelphia, USA.
2. 'Prioritizing factors for selection of hospital waste contractors', *Journal of Applied Management Science*.

# STUDIES ON MODELLING APPROACHES IN SOLID WASTE MANAGEMENT

THESIS

SUBMITTED FOR THE AWARD OF THE DEGREE OF

**Doctor of Philosophy**

IN

**CIVIL ENGINEERING**

BY

**SHEEBA KHAN**

Under the Supervision of

**Dr. I.H. FAROOQI**

DEPARTMENT OF CIVIL ENGINEERING
Z.H. COLLEGE OF ENGINEERING AND TECHNOLOGY
ALIGARH MUSLIM UNIVERSITY
ALIGARH (INDIA)

**2010**

# Department of Civil Engineering

**Faculty of Engineering & Technology**

**Aligarh Muslim University, Aligarh 202002 (India)**


## CERTIFICATE

*This is to certify that the thesis entitled 'STUDIES ON MODELLING APPROACHES IN SOLID WASTE MANAGEMENT', submitted by Ms. Sheeba Khan, for the award of the degree of the Doctor of Philosophy in Civil Engineering (Environmental Engineering), AMU, Aligarh, is a record of her own work carried out by her under my supervision.* a

*It is further certified that the work presented in this thesis has not been submitted for the award of any degree elsewhere.*

*Dr. I. H. Farooqi*

*Associate Professor*

*Department of Civil Engineering*

# ACKNOWLEDGEMENTS

*I sincerely want to thank and express my gratitude towards my supervisor Dr. I.H. Farooqi for his valuable guidance, supervision and encouragement throughout the course of my research work. His continual support and guidance during the course of interactions has led to the development of a new perspective towards research.*

*Thanks are due to Prof. Razaullah Khan, Chairman, Department of Civil Engineering for his cooperation. Thanks are due to Prof. Mohd. Jamil, former Chairman of the Department of Civil Engineering, for giving me the opportunity and encouragement to accomplish this work.*

*I take this opportunity to thank all the members from the section of Environmental Engineering for their support. I also want to thank the supporting staff of the Environmental Engineering Section. My thanks are due to my fellow research scholars for their cooperation during my work.*

*I also want to thank my parents whose blessings have made this work a reality. My sincere thanks are due to my husband whose continual moral support and sometimes academic suggestions instilled new energy to work hard.*

*Lastly, I want to thank my daughter, whose unconditional love has been the biggest source of inspiration for me to take on new challenges and continuously strive to move ahead in life.*

Sheeba Khan

*Sheeba Khan*

## TABLE OF CONTENTS

## S. No. List of Tables

S. No.

# List of Figures

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

Over the years, there has been a continuous migration of people from rural and semi-urban areas to towns and cities. This uncontrolled growth of urban areas has led to deficiency in infrastructural services, in Indian cities, such as water supply sewage and municipal solid waste management (MSWM). It has been estimated that the urban population of 285 million is concentrated in a few large cities and 32 metropolitan cities, which account for 34.5 percent of the urban population; expected to reach 341 million by 2010 (Census of India, 2001). The annual rate of growth of urban population in India is 3.09%. The proportion of population living in urban areas has increased from 17.35% in 1951 to 26.15% in 1991(CPCB, 1999). The number of Class I cities with population exceeding 1, 00,000 has increased from 212 to 300 during 1981 to 1991 (CPHEEO, 2000). It is interesting to note that as much as 65.2% of the urban population is living in these Class I cities. The growth in generation of municipal solid waste (MSW), in recent years, has been exponential due to the booming Indian economy. There has been increased change in the standard of living in the urban areas of the country, which has left the civic authorities in a tight spot. The waste quantities are estimated to increase from 46 million tones in 2001 to 65 million tones in 2010 (Kumar and Gaikwad, 2004). Most urban areas in the country are suffering from lack of solid waste management (SWM) problems, despite the fact that large sums of municipal expenditure is earmarked for it. According to Flintoff (1984), SWM takes up to 1% of GNP, and Cointreau (1982) estimated that it consumed about 20% to 40% of municipal revenues in developing countries.

Solid waste management (SWM) may be defined as the discipline associated with the control, generation, storage, collection, transfer and transport, processing and disposal of solid wastes in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations. and that is also responsive to public attitudes. In its scope SWM includes all administrative.

financial, legal, planning, and engineering functions involved in solutions to all problems of solid wastes. The solutions may involve complex interdisciplinary relationships among such fields as political science, city and regional planning, geography, economics, public health, sociology, demography, communications, and conservation as well as engineering and material science. (Tchobanoglous et al., 1993)

Most of the municipal corporations of the country under whose purview SWM of cities lie are unable to meet the national and international standards owing to non-availability of adequate expertise and experience; resulting in improper handling of solid wastes, which further leads to environmental degradation and health hazards. Moreover, the municipal solid waste management (MSWM) is under taken by the civic agencies that are fund starved. Therefore, use of appropriate and effective resources such as technology, equipments and human resources becomes difficult, which leads to wide-spread public discontent. MSWM issues have moved to the fore of the public agenda, with levels of concern and activity by citizens and governments world-wide reaching unprecedented levels (Read et al., 1997). The lack of funds makes it crucial for the civic authorities to perform in the best capacity, avoid any failures of the strategies and in important selections. With the stellar growth in the Indian economy, the amount of generated waste is rising, resulting in overburdened labor and an increase in the cost of operation of MSWM. Therefore, it is imperative that effective and appropriate programs should be investigated for the improvement of a solid waste management system in the urban areas of the developing countries (Tin et al., 1995).

Another important segment of the SWM, apart from the municipal waste, that needs urgent attention in developing countries such as India, is the bio-medical or the hospital waste. The most authentic definition from the WHO characterizes health-care waste (HCW) as those wastes generated from hospitals, medical centers, health-care establishments and research facilities in diagnosis, treatment, immunization and associated research (Ananth et al., 2010). A hospital is a center that provides various health-care services to the community. Its activities may include curative, rehabilitation, preventive and promotion of health education. In undertaking the activities, the hospital may also generate wastes both from medical and non-medical activities. The infectious components in the hospital wastes could pose a potential risk to the patients, neighboring communities, hospital staff (especially waste workers), visitors and even the surrounding environment. This area of waste management is grossly neglected. Infectious and non-infectious wastes are not segregated at the source and are taken to incineration plant in unhygienic manner. The system adopted for the collection, transportation, and disposal of hospital waste lacks scientific and efficient design.

Public sector planning and management problems, such as solid waste management, are challenging and complex. In addition to the modeling challenges and computational complexities, the multi-objective nature of these problems adds another dimension to the complexity. Specifically, decision-makers responsible for environmental control, policy and management problems are faced with a vast array of alternatives from which the most appropriate must be identified for implementation. In addition to cost-effectiveness, consideration must to be given to public health, social acceptability, political feasibility, equity among all affected parties and environmental performance such as emissions and energy consumption. Further, the decisions affect multiple interest groups with often competing goals. Formal methods have been developed to aid decision-makers in converging to the best compromise solution that integrates their preferences on multiple criteria. These methods are developed in the area of study that is generally referred to as multiple criteria decision making (MCDM).

## 1.2 MOTIVATION FOR RESEARCH

According to MoEF (2010), the Ministry of Urban Development (MoUD) assessed MSW generation in the country to be 1, 00,000 metric tons or 0.1 million metric tones per day (MMT/d) in the year 2001-02. The Central Pollution Control Board (CPCB) made a survey of 59 cities in India during the year 2004-05 to assess the existing status of MSW management which included 35 metro cities and 24 state capitals. Based on this study and on census data of 2008, the MSW generation in the country has been estimated to be 0.573 MMT/d in the year 2008. This staggering amount of the waste generated in India warrants that effective management tools should be adopted in order to solve the conundrum of the SWM. Moreover, the World Bank (1999) states that the problem of SWM is beyond the ability of the municipal governments and they need assistance from the other levels of government, businesses and the general community to combat the problem of mismanagement of solid waste. It mentions that parts of India may face greatest waste management challenge in addition to other Asian countries; such as Indonesia, Philippines, and parts of China; since the projected waste generation rates and relative affluence may exacerbate the problem.

The conventional waste collection and disposal system in India consists of garbage trucks, a landfill and incineration, in case of health-care waste. However, the growing trend in the world for disposal of solid waste is towards implementing waste diversion and creating an integrated solid waste management (ISWM) system (Environment Canada, 2000; Chang et al., 2005). India as a country is moving towards this goal of implementing ISWM in a number of SWM areas; the government and the law enforcing agencies, such as the Supreme Court of India, are pushing towards this goal by promulgating and making mandatory MSW segregation in 2004 and bio-medical waste rules in 1998. The performance audit report on management of waste in India submitted by the office of the Comptroller and Auditor General (CAG) in September 2008, surmised that the waste management hierarchy (avoiding generation of waste, followed by reducing, reusing, recycling, recovering, treating and disposing whatever waste is produced) needs to be emphasized in the national policies and summarized its observations on the current waste management situation in the country (MoEF, 2010). In one of its report on waste management MoEF (2010) states "Selection of sites for locating landfills, incinerators, composting plants could become contentious, often opposed by people living in the vicinity of the proposed site and along the expected route of waste transportation. Addressing their concerns, stakeholder consultation, methods to meet costs of ensuring public safety, pollution and odor control, besides arranging alternate land/route, adopting safer and viable technologies, have to be implemented by the service providers". Thus, the conventional management is inadequate due to the complexities existing in such a difficult effort, which involves collection techniques to be used, transport route to be taken up, levels of services to be offered, and facilities to be adopted. Moreover, many related processes and/or factors are complex with interactive, dynamic and uncertain features for example, the continuous change in the quantity of municipal waste in a given area and the quality of the infectious waste in the health-care institutions. Therefore, a systems' approach for analyzing waste management is desired, in order to support decisions of short-term waste management operation and long-term strategic planning.

The modeling enables decision- makers and solid waste managers to approach and tackle waste issues more judiciously and scientifically. The models allow them to arrive upon specific waste management system with in-depth knowledge of the methodology and enable to understand the sensitivity of the different factors that are in the system. Thus, making the decision-makers to learn how changes in the system contribute to the environmental impacts and health hazards through an overall scenario analysis. Moreover, applying the models to several solid waste management systems allows determination of which system shows the best performance from an environmental and managerial perspective.

## 1.3 SCOPE OF THE RESEARCH

The focus of the work presented in this thesis on the methods to solve SWM problems through modeling. The empirical study was carried out in Delhi the capital of India. The area falling under the purview of the major civic body Municipal Corporation of Delhi (MCD) was undertaken for the study. In addition to this, data from other Class I cities, apart from Delhi, is also utilized to model MSWM problems.

Data obtained, through an exhaustive survey and interaction, from the small and medium hospitals in Class I cities was used to model the infectious waste or the bio-medical or the hospital waste models.

## 1.4 OBJECTIVES OF THE RESEARCH

The objective of this thesis is to use the available MCDM techniques in order to assist people involved in managing the solid wastes. This dissertation is divided in two parts: first MCDM techniques have been applied to municipal solid wastes (MSW) and second, the same techniques have been applied to hospital waste scenario. The major objectives of the thesis are:

- To understand that SWM is part of broader urbanization problem.
- To understand the attitude of the people towards SWM.
- To develop a framework to model and prioritize the different factors of (a) MSWM plan and (b) infectious waste management.

- To develop a framework for the selection of the best alternative available to formulate a solid waste plan
- To develop a framework to understand the relationship among the various enablers and barriers of MSW and hospital waste.

## 1.5 RESEARCH MEHEDOLOGY

1. *Fuzzy Analytic Hierarchy Process (Fuzzy-AHP):* AHP is a decision-making methodology used to solve multi-criteria decision problems. This method has been used in fuzzy form to prioritize factors for modeling of MSWM and for prioritizing factors for selection of infectious waste management contractors as well.

2. *Analytic Network Process (ANP):* ANP is used as a tool to solve multi-criteria decision making problems. In this research ANP is used to select the best alternative to disposal options in MSWM and select the best infectious waste firm for the handling of the hospital waste. It provides opportunity to the researcher to simultaneously consider the impact of criterion, sub-criterion and their interrelationships to select the best alternative under consideration.

3. *Questionnaire based survey:* This is used to gain a broad insight into the public psychology towards MSWM per se, waste generation habits and problem areas of SWM Indian cities. A questionnaire based study was conducted in the areas, where Japanese International Cooperation Agency (JICA) funded pilot project for the segregation of MSW was undertaken by MCD in 2004. The study was then compared with the similar survey based in another Asian city Doha, capital of the state of Qatar.

4. *Interpretive Structural Modeling(ISM):* It is used for analyzing different interactions among different barriers in MSWM and HWM. It is also employed to find the key variables, which are of strategic nature and management is required to carefully focus on them to improve other dependent variables of the system.

## 1.6 RESEARCH OVERVIEW

An extensive literature review was undertaken to understand the gaps in the area of SWM. Based on the literature review and discussion with the SWM experts, a questionnaire was developed for conducting a survey on problem areas in India. The area selected for this purpose is the Class I city Delhi. Results from descriptive analysis of the questionnaire survey and insights from the literature have been used to develop various mathematical models discussed earlier. These frameworks provide the prioritization of the various factors, selection of the various end-options and understand various interactions among the barriers to effective SWM. A brief description of all the chapters is as follows:

***Chapter 1***

The first chapter of the thesis gives brief description about the stats quo of the SWM and the potential issues that India may have to deal with due to the burgeoning population. Motivation of research and objectives of this research have been presented. Finally, an overview of chapters- scheme of the dissertation has been reported in this chapter.

***Chapter2***

The second chapter contains a classification of the literature related to SWM. Through this literature review the gaps in the contemporary research in this area have been identified. These gaps are major driver for current research.

***Chapter 3***

The objective of the third chapter is to propose a fuzzy analytic hierarchy process (Fuzzy-AHP) framework to provide both municipal solid waste management and hospital waste management experts a more effective and efficient model for prioritizing MSWM factors and for selection of contractors involved in HWM.

***Chapter 4***

The fourth chapter introduces a hierarchical network (hiernet) decision structure and applies the analytic network process (ANP) super-matrix approach to measure the relative desirability of disposal alternatives for MSW using value judgments as the input of the various stakeholders. This chapter also includes ANP method to objectively select infectious waste disposal contractors based on the results of interviews with experts in the field, thus reducing overhead costs and enhancing medical waste management.

*Chapter 5*

The fifth chapter is a questionnaire based study in the cities of Delhi, India and Doha, Qatar for the major areas of dissatisfaction, in management of municipal solid waste, of the residents. The chapter provides an insight in to the existing MSWM plans of the two cities and helps understanding the trends in the household waste generation in the two cities as well.

*Chapter 6*

The next chapter presents the interpretive structural modeling (ISM) this research presents a hierarchy based model and the mutual relationships among the barriers of MSW and waste management in hospitals. This classification provides a useful tool to waste management professionals to differentiate between independent and dependent variables and their mutual relationships which would help them to focus on those key variables that are most important for effective waste management both in cities and hospitals.

*Chapter 7*

The last chapter, summary, limitations and scope for future work, presents the summary of the conducted research. Research findings and major implications of this research have also been presented in this chapter. The chapter concludes with the limitations of the present study and scope for future research.

## 1.7 CONCLUSION

This chapter, introduction, includes an overview of the context related to this research. Modeling aspects in solid waste management, as a field of research is introduced as the prime focus for the present work. The objectives of the research and a brief description of research methodology to be used in this research and the scope of the present research have also been presented. In the research overview, a brief summary of the entire research reported in this thesis has been presented. The chapter organization scheme of this thesis is also presented below in figure 1.1.

## 1.8 ORGANIZATION OF THE THESIS

The following figure depicts the organization of the thesis

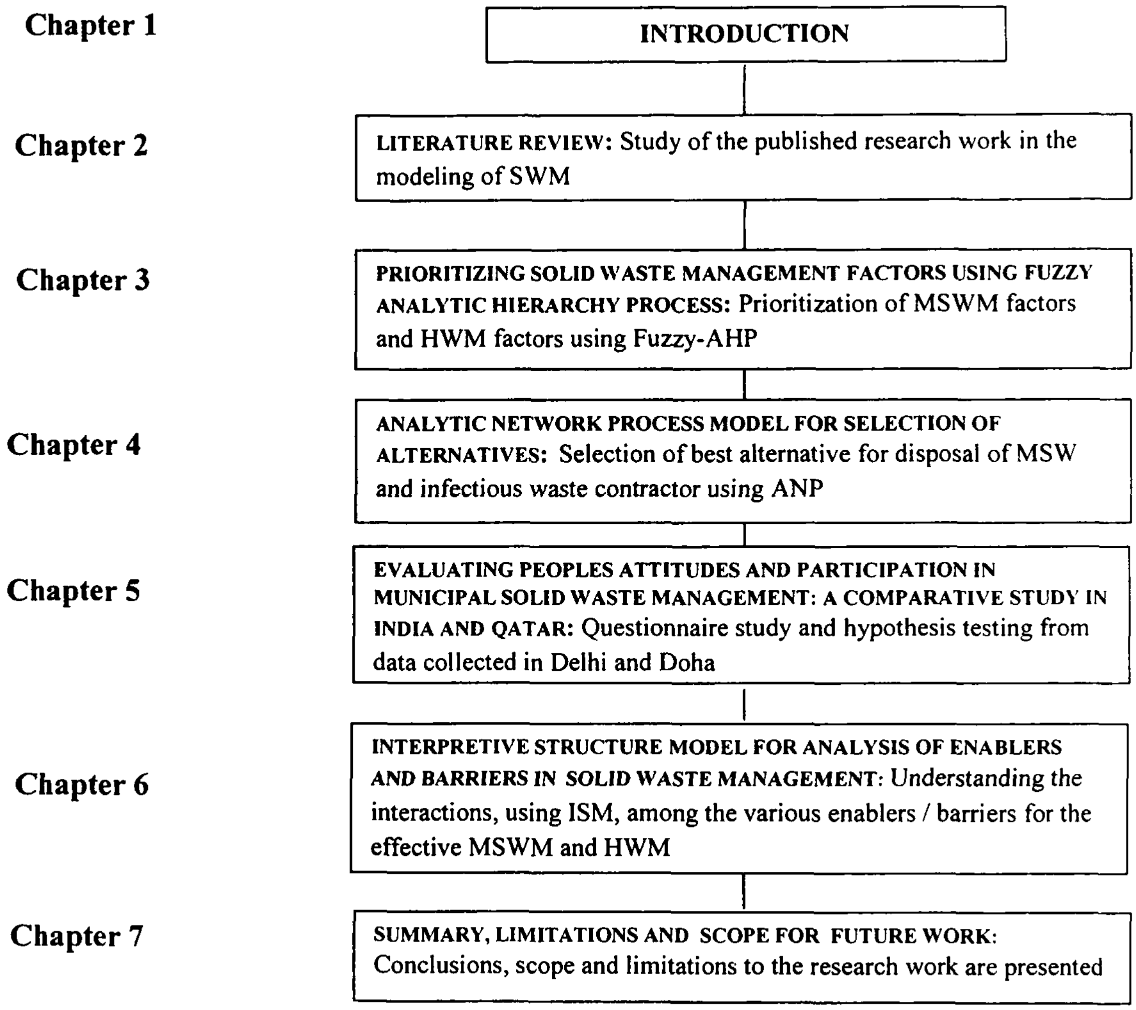


**Figure 1.1: Chapter organization of the thesis**

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

A major part of the world today has a throwaway culture, producing huge amounts of solid wastes. Advancements in environmental measurement techniques clearly indicate that demand on the earth's resources is not sustainable and should be addressed immediately (York et al., 2004). What should be the correct balance between environmental, economic, technical, social and regulatory factors, when one solid waste system designed and implemented? What must be the right fraction of the waste recycling, composting, reduction and recovery options in the scheme? How much community participation is essential for the success of a MSWM scheme? What should be the major criteria for outsourcing bio-medical waste management (BMWM)? What are the major elements that may inhibit or encourage any kind of SWM plan? All these questions need to be answered before the commencement of any solid waste management operation. To make such a scheme efficacious it is important that it is environmentally sustainable, economically viable and socially acceptable (Nilsson-Djerf and McDougall, 2000; Khan and Faisal, 2008).

---

*Part of this chapter has been accepted for publication as:*

*'Some Major Issues in Municipal Solid Waste Management: A Review', (2010)* ***International Conference on Emerging Technologies for Sustainable Environment, Aligarh, India***

*'Biomedical Waste Management: Issues and Challenges', (2010)* ***International Conference on Emerging Technologies for Sustainable Environment, Aligarh, India***

Abundant literature exists in solid waste management (SWM) research that discusses problem areas affecting the efficacy of the SWM schemes. However, there is limited research that has explicitly addressed the issues of environmental sustenance, economical viability and social acceptance together within the context of municipal solid waste and hospital waste management. In fact, a study conducted by Morrissey and Browne (2004a) concluded that no computer software waste management tools currently integrate all three aspects so and so cannot be considered fully sustainable.

Rogers (2001) classifies models into two broad categories: those that use optimizing methods and those that use compromising methods. Though Rogers categorized the models in the context of the engineering project appraisal, but it is valid for the waste management models as well. Optimizing models assume that the various goals of the plan can be expressed on a common scale of measurement. The loss in one objective or goal can be thus, evaluated against a gain in another. Cost-benefit analysis and present worth evaluation with the common scale of measurement usually expressed in monetary terms are integral part of the optimization models. On the other hand, compromising methods are based on the assumption that the decision- maker may have limited knowledge regarding the decision situation and are based on Simon's Simon (1976) concept of 'bounded rationality'. Guitouni and Martel (1998) also mention that the ''idea of the optimal solution is abandoned for the notion of the 'satisfaction of the decision- maker and that this is the beginning of the development of many multi-criteria decision analysis (MCDA) methods.'' The basic principle behind these methods is that any feasible solution is an optimal compromise among the various priorities. The discrepancies between the actual outcomes and aspiration levels are traded off against each other by means of preference weights. Each given alternative is analyzed in relation to multiple priorities, so that the best chosen alternative is the one that performs efficaciously well according to the priorities identified (Morrissey and Browne, 2004a).

An exhaustive literature review identified numerous models developed for MSW management and planning. In recent years, many works have been presented with the aim of providing useful and comprehensive decision models, which should be both significantly close to reality and computationally tractable in order to help planners in managing solid waste disposal and treatment in urban areas, taking into account multi-disciplinary aspects involving economic, technical, normative, and environmental sustainability issues. Earlier, the studies have indicated that the emphasis were on model formulation, rather than on issues such as usability and data requirements. A technical survey conducted by Barlishen and Baetz (1996) indicated that the available mathematical modeling techniques were not widely utilized in practice, particularly in municipal or regional waste management agencies. Waste management engineers and planners required additional tools to assist in the development and evaluation of integrated MSW management systems, particularly as the knowledge and technological options in this field continue to expand. There is both a need for, and an interest in, a useful, practical (with respect to data requirements and cost) and reasonably objective form of decision support system for use at the municipal and regional MSW management decision-making levels.

In the past several decades, considerable research efforts have been directed towards the development of economic-based optimization models for MSW flow allocation. As Berger et al. (1999) and Tanskanen (2000) point out, the first solid waste management models were optimization models and dealt with specific aspects of the problem, for example vehicle routing, Truitt et al. (1969), or transfer station siting, Esmaili (1972). However, according to Berger et al. (1999), the early models suffered from several shortcomings such as having only one time period, recyclables rarely being taken into account, having only one processing option of each type, or having a single generating source. A more recent model presented by Chang and Chang (1998), is based on the minimization of an overall cost (taking into account energy and material recovery requirements), which takes place through the solution of a constrained non-linear optimization problem. However, this model does not take into account normative, environmental and technical aspects. Fiorucci et al. (2003) presented a decision model, based on the same approach as Chang and Chang (1998), but within a more general modeling framework, both as regards the system representation and the decision variables considered. However, an approach merely based on economic considerations cannot be considered as completely satisfactory in connection with waste management problems.

The system boundaries for the MSWM models developed during the 1980s got extended with advancement in research and acknowledgement of the persisting problems in SWM. Thus, the new models comprehensively analyzed the relationships between each factor in the waste management system, rather than looking at each in isolation (MacDonald, 1996a). Further, the increase and availability of the computers provided an opportunity to develop more sophisticated waste management models. The models developed in the 1980s were mainly aimed at minimizing the costs of mixed waste management (Gottinger, 1988) with intermittent inclusion of and recycling in some (Englehardt and Lund, 1990). As pointed out by Morrisey and Browne (2004a) the main issues of concern for these early models were generally economic, some researchers did acknowledge the social equity issues related to the siting of facilities (Fuertes, 1974). Similarly, Kirca and Erkip (1988) developed a linear programming model for determining transfer station locations in the MSW management system of Istanbul, Turkey. Other researchers, such as Jacobs et al. (1984); Motameni and Falcone (1990) included social issues. They looked at ways to influence people's attitudes, so that they might change their behavior when it comes to recycling. However, the inclusion of social issues such as these was unusual.

According to Leão et al. (2004) conventional waste models, in the late 1980s and 1990s, started to include waste recovery facilities, and assumptions of waste reduction. The optimizing function was generally still based on economic analysis, with the difference that revenues from waste recovery, and/or environmental costs of pollution were included. Jacobs and Everett (1992) and Lund (1990), for example, developed models that schedule landfills and waste recovery activities by minimizing the present value cost over the landfills lifetime. According to the state-of-art review on solid waste management conducted by Morrisey and Browne (2004), models developed by MacDonald (1996b), Chang (1996) was the first to explicitly incorporate environmental costs. With similar approach, the model developed by Daskalopoulos et al. (1998) identifies the optimal combination of technologies for the handling, treatment and disposal of municipal solid wastes according to economic and environmental criteria.

1990s saw the advent of more comprehensive waste management models. Chang and Wei (1999), MacDonald (1996b), Morris (1991) and Smith and Baetz (1991) developed models that included recycling and other waste management methods for the planning of municipal solid waste management. Or and Curi (1993) applied a mixed integer linear programming model to improve solid waste collection and transportation system in the city of Izmir, Turkey, with the aim of minimizing the city's total solid waste collection and transportation costs. A cost–effective and workload-balancing operation in the regional solid waste management system of the Taipei City was developed by Chang et al. (1997) by using linear and integer programming methods. Integrated solid waste management (ISWM) gradually became the norm of the waste management models (Berger et al., 1999; Clift et al., 2000; EPIC and CSR, 2000; ERRA, 1999; Gabola, 1999; Kowalewski et al., 1999). ISWM takes into account of all the aspects such as, full range of waste streams to be managed, to develop a SWM plan. It selects the best available waste management practices, based on site specific environmental and economic considerations, to solve any SWM problems. Thus, a trend to include the whole life cycle of products in models has emerged (Barton et al., 1996; Bjorklund et al., 1999; EPIC and CSR, 2000; Finnveden, 1999; Harrison et al., 2001; McDougall et al., 2001; Powell, 2000; Warmer Bulletin, 2000), so as to assess the environmental impact thoroughly from various significant activities during its life cycle. Smith and Baetz's (1991) research also shows that until the 1990s, there was very little literature available detailing costing information on integrated waste management systems.

As mentioned before, most waste management models consider economic and environmental aspects, but very few consider social aspects. For a waste management system to be sustainable, it needs to be environmentally effective, economically affordable and socially acceptable. Nilsson-Djerf and McDougall (2000), who go on to say, ''for a waste management system to be effective, it must be accepted by the population''. This point is further emphasized by Petts (2000), who states, ''the most effective management of MSW has to relate to local environmental, economic and social priorities'' and must go beyond the traditional consultative approaches that require the ''expert'' to draft the solution in advance of public involvement to a much more effective approach by involving the public before key choices have been made.

Recent models echo a change in strategy by incorporating more profound issues that have been plaguing the effective management of solid wastes. Solid waste planning is not only being refurbished from relying solely on landfilling, to a wider range of waste management techniques based on the principle of ISWM, but also on more sociological and political aspects. Multiple attribute decision system (MADS) developed by Montano and Zandi

(2000), treats SWM as a squishy problem and provides managerial and decision support for solid waste policymakers. MADS provides a comprehensive systems approach for solid waste system evaluation, decision support, accountability, and defensible solutions. Such an approach is particularly important for solid waste decision making because of the emotional and political nature of policy implementation.

## 2.2 MULTI CRITERIA DECISION MAKING

From the entire discussion in the section above, it can be deduced that planning a MSW management system is essentially a very complex task, because it is necessary to consider conflicting objectives at the same time; moreover, such problems are generally overwhelmed by financial feasibility and environmental viability. Due to these reasons several authors (Chang and Wang, 1997a, b; Hokkanen and Salminem, 1997; Karagiannidis and Moussiopoulus, 1997) chose to introduce and apply multi- criteria decision techniques.

Bana e Costa et al. (1997) provides a brief history of the origins of multi criteria evaluation methods. Benjamin Franklin provided a profound insight into the multi criteria formulation of decision problems in 1772, when he used structuring and evaluation to solve problems with conflicting criteria and uncertainty, but it was not until 1972 that the term multiple-criteria decision-making (MCDM) was introduced into management science in the United States. Over the past two decades, MCDM has developed into a discipline in its own right, as is evidenced by the impressive bibliographic survey of Steuer et al. (1996) with a specialist journal of its own, the Journal of Multi-Criteria Decision Analysis (JMCDA), starting publication in 1992.

MCDM has been explored and applied to a number of real-life problems in recent years. The basic principle of the MCDM is that it takes several and often conflicting criteria into account to work out an optimal solution to the problem. This multi-dimensional approach leads to a more robust decision making rather than optimizing a single dimensional objective function (such as cost-benefit analysis). Further, the multi-criteria approach enables decision-makers to know about the problem and the alternative courses from several perspectives. The normal approach is to identify several alternatives (such as different waste management scenarios), which are then evaluated in terms of criteria that are important for the model or circumstances of the model being developed. The result is a ranking of the alternatives. The type of criteria chosen in these model types depends on the objectives of the model, and therefore could include risk assessment or environmental impact assessment. A detailed description of the various MCDM techniques can be found in Brans et al. (1998) (PROMETHEE), Jacquet-Lagreze and Siskos (1982) (UTA), Keeney and Raiffa (1976) (MAUT), Roy (1991) (ELECTRE), Saaty (1980) (AHP), and Zeleny (1982) (Multiobjective Optimisation). Further details on comparing the main MCDM techniques can be found in Bana e Costa et al. (1997), Guitouni and Martel (1998), Rogers (2001), Salminen et al. (1998), van Huylenbroeck (1995) and Zopounidis and Doumpos (2002).

## 2.3 LITERATURE REVIEW ON RESEARCH METHODS

### *2.3.1 Fuzzy Analytic Hierarchy Process (Fuzzy-AHP)*

The analytic hierarchy process (AHP) is a theory of relative measurement on absolute scales of both tangible and intangible criteria based on paired comparison judgment of knowledgeable experts. Comparisons are our biological heritage, neglected in science because there has not been any effective way to show how direct numerical judgment can serve as a tool of measurement and how a valid scale of priorities can be derived from these measurements (Ozdemir and Saaty, 2006). The measurement of the intangibles working in tandem with the tangibles is the main concern of the AHP; to make the decision-making a more objective rather than a subjective exercise. The AHP has been validated with numerous examples in applications that have been published in the literature, ranging from prediction of the turn around date of the US economy done twice, once in the 1990s and again in 2001, to predicting the outcome of the presidential elections since 1976, to who would win the next world chess championship match and by how many games, to dozens of exceedingly accurate predictions of the market share of different companies in a business, to the average number of children per family in rural India, to the percentage of Alaskans voting for and against prospecting for oil and so on. These examples are particularly useful for checking on the accuracy of the numbers provided and the numbers derived to validate the process (Ozdemir and Saaty, 2006; Whitaker, 2007).

Despite of its wide range of applications, the conventional AHP approach may not fully reflect a style of human thinking. One reason is that decision-makers usually feel more confident to give interval judgments rather than expressing their judgments in the form of single numeric values. As a result, fuzzy AHP and its extensions are developed to solve alternative selection and justification problems. Although fuzzy AHP requires monotonous computations, it is capable of capturing a human's appraisal of ambiguity when complex multi-attribute decision-making problems are considered. For details on the use of AHP and its various calculations, the reader is referred to the work of Saaty (1980). Chang (1992; 1996) developed a fuzzy extent analysis for AHP, which has similar steps as that of Saaty's crisp AHP. However, his approach is relatively easier in computation than the other fuzzy AHP approaches. The following table 2.3.1 delineates the application of fuzzy- AHP to various managerial and selection problems (Khan and Farooqui, accepted).

**Table 2.3.1: Various applications of fuzzy-AHP**

| S. No. | Application | Reference(s) |
|---|---|---|
| 1. | Mobile commerce | Büyüközkan G. (2009) |
| 2. | Human Capital | Bozbura et al. (2007) |
| 3. | Hospital site selection | Vahidnia et al. (2009) |
| 4 | Energy Policy | Kahraman and Kaya (2010) |
| 5 | Bridge Construction | Pan (2008) |
| 6 | Municipal Solid Waste Management | Khan and Farooqui (accepted) |
| 7. | Eco-environmental vulnerability assessment | Li et al. (2009) |

### *2.3.2 Analytic Network Process (ANP)*

In general, analytic hierarchy process (AHP) is a widely used method to model multi-criteria decision making problems. However, a significant limitation of AHP is the assumption of independency among various criteria of decision-making. Analytic network process (ANP), on the other hand, captures interdependencies among the decision attributes and allows a more systematic analysis. It also allows inclusion of all the relevant criteria (tangible or intangible, objective or subjective, etc.) that have some bearing in arriving at the best decision (Saaty, 1996). ANP provides a more generalized model in decision-making without making assumptions about the independency of the higher-level elements from lower-level elements and also of the elements within a level (Khan and Faisal, 2007).

The ANP consists of coupling of two phases. The first phase consists of a control hierarchy of network of criteria and sub-criteria that control the interactions. The second phase is a network of influences among the elements and clusters. The network varies from criteria to criteria and thus different super-matrices of limiting influence are computed for each control criteria. Finally, each one of these super-matrices is weighted by the priority of its control criteria and results are synthesized through addition for the entire control criterion (Saaty, 1996).

Some of the fundamental ideas in support of ANP are (Saaty, 1999; 2001):

- ANP is built on the widely used AHP technique
- ANP allows for interdependency, therefore ANP goes beyond AHP
- ANP technique deals with dependence within a set of elements (inner dependence) and among different sets of elements (outer dependence)
- The loser network structure of the ANP makes possible the representation of any decision problem without concern for what criteria comes first and what comes next as in a hierarchy
- ANP is a non-linear structure that deals with sources, cycles and sinks having a hierarchy of linear form with goals in the top level and the alternatives in the bottom level
- ANP portrays a real world representation of the problem under consideration by prioritizing not only just the elements but also groups or clusters of elements as is often necessary and
- ANP utilizes the idea of a control hierarchy or a control network in dealing with different criteria, eventually leading to the analysis of benefits, opportunities, costs, and risks.

The following table 2.3.2 enlists some of the application in ANP.

**Table 2.3.2: ANP application to some of the problems**

| S.No | Application | Reference(s) |
|---|---|---|
| 1 | Supply chain risk management | Faisal et al. (2007a) |
| 2 | IT outsourcing | Faisal and Banwet (2009) |
| 3 | Municipal solid waste disposal | Khan and Faisal (2007) |
| 4 | Siting for MSW plant | Aragonés-Beltrán et al. (2010) |
| 5 | Telecommunications | Lee et al. (2009) |
| 6 | Supplier selection | Demirtas and Üstün (2008) |
| 7 | Emergency management | Levy and Teji (2007) |

### *2.3.3 Interpretive Structural Modeling (ISM)*

Interpretive structure modeling (ISM) methodology helps to impose order and direction on the complex relationships among elements of a system (Sage, 1977; Warfield, 1974). ISM is an interactive learning process whereby, a set of different directly and indirectly related elements are structured into a comprehensive systemic model. The model so formed portrays the structure of a complex issue, a system of a field of study, in a carefully designed pattern employing graphics as well as words. For complex problems, like infectious waste management in hospital, a number of variables may be affecting the system. However, the direct and indirect relationships between the variables describe the situation far more accurately than the individual variable taken into isolation. Therefore, ISM develops insights into collective understandings of these relationships. ISM has been applied by a number of researchers to develop a better understanding of the systems under consideration.

**Table 2.3.3: ISM applications found in literature**

| S. No. | System under consideration | Reference(s) |
|---|---|---|
| 1. | Energy Conservation | Saxena et al. (1992) |
| 2. | Vendor Selection | Mandal and Deshmukh (1994) |
| 3. | Waste Management in India | Sharma et al. (1995) |
| 4. | Sustainable supply chains | Faisal (2010) |
| 5. | Barriers of IT enablement of supply chains | Jharkharia and Shankar (2005) |
| 6. | Supply Chain risk management | Faisal et al. (2007b) |
| 7. | Strategic Decision Making | Bolaños et al. (2005) |
| 8. | Supply chain agility | Faisal et al. (2007c) |

The ISM methodology is interpretive from the fact that the judgment of the group decides, whether and how the variables are related. It is structural too, as on the basis of relationship; an overall structure is extracted from the complex set of variables. It is a modeling technique in which the specific relationships of the variables and the overall structure of the system under consideration are portrayed in a digraph model. ISM is primarily intended as a group learning process, but it can also be used individually. A detailed description of the ISM is given in section 6.5.

## 2.4 LITERATURE CLASSIFICATION SCHEME

In this research, literature review on solid waste management has been classified into two categories:

1. Municipal Solid Waste Management (MSWM)
2. Hospital Waste Management (HWM)

### *2.4.1Municipal Solid Waste Management (MSWM)*

With rapid urbanization municipal solid waste (MSW) problems are becoming more complicated, making the waste management policies more numerous, complex and cumbersome to implement. In the past couple of decades, decision-making in MSWM has undergone a drastic change from deciding collection systems (Esmali, 1972; Helms and Clark, 1971) or determining transportation or transfer of solid waste (Truitt et al., 1969) to cost-effective MSW planning (Hasit and Warner, 1981; Jenkins, 1982; Perlack and Willis, 1987). As MSW policies became more complicated, the factors to be considered also increased; hence, several MSWM models with deeper analysis emerged. The factors considered in MSWM models were mainly economic (e.g., system cost and system benefit), environmental (air emission, water pollution) and technological (the maturity of the technology).

*People's behavior towards MSWM*

According to Sudhir et al. (1996), it is reported by Gotoh (1989) that MSWM should not be viewed from a narrow perspective of collection and disposal, but should instead be seen as a part of issues arising out of rapid urbanization. Expressing a similar view-point, Furedy

(1990) states that MSWM is basically a socio-cultural problem, which would limit the effectiveness of a techno-managerial approach. Furedy (1992) also observes that solid waste planning in developing countries does not focus on the concept of 'resource recognition', i.e. treating waste as an unused resource. She therefore calls for a nonconventional approach ('soft') involving community-based initiatives and informal mechanisms to MSWM. The conventional or the hard approach of managing MSW includes techno-managerial approach, which is an efficient system that reduces multiple handling of waste, allows smooth flow of waste from various collection points to the disposal sites, and facilitates disposal of waste in an environmentally safe manner. Thus, another concern about the hard approach is that the planning process is top-down in nature, which as Douglass (1992) notes, may not work in favor of the urban poor. With more insight in the MSWM it has been reported that not only in the developing world, but also in the developed countries the management of solid waste entails a lot of psychological aspects. A number of studies have been carried out to study the public attitude pertaining to the municipal and house-hold waste per se and to encourage the public participation in the MSWM plan in a given area. A number of researchers carried out research to study the determinants and motives that drive the public participation towards recycling, reuse, waste minimization and other municipal solid waste issues. The existing literature provides a fair insight about the role of motives in the performance of recycling behavior. People, who are motivated enough, are most likely to participate (Katzev et al., 1993), but these motives may differ from people to people. Early research on recycling motives focuses on distinguishing the effects of intrinsic versus extrinsic motives on people's behavior. Several studies such as, DeYoung (1984) and Jacobs and Bailey (1982) designed within a behavioral paradigm confirmed through the application of behavioral interventions that external rewards motivate people to recycle. However, one large disadvantage with the extrinsic rewards is that the behavior of the people returns to the baseline once they are withdrawn (Witmer and Geller, 1976). Thus, extrinsic rewards are insufficient over the long run to maintain recycling behavior, making the environmental awareness all the more important. A more recent study undertaken by Shaw and Maynard (2008) indicates that the extrinsic rewards such as financial incentives can not be completely disregarded, as they have a favorable influence if introduced as community-based rewards and household-specific council tax rebates.

*Insufficient information regarding participation in MSWM schemes*

Focused knowledge dissemination about the environmental consequences of different waste management systems, as well as useful knowledge about convenient and practical solutions, were seen as important criteria for recycling behavior in the research conducted by Refsgaard and Magnussen (2009). They found that people wanted to know more about the consequences of different municipal waste management and recycling alternatives. According to Massoud et al. (2003), social barriers can be overcome as well if proper information dissemination and the need for the integrated approach are thoroughly communicated to the targeted community. Tonglet et al. (2004) suggest that waste minimization and recycling behavior is likely to be influenced by a concern for the environment and the community, appropriate opportunities and consequences of recycling, but most probably to be repressed by perceptions of inconvenience and lack of time and knowledge. Similar findings were published by Ebreo and Vining (2000), who found that the support for educational programs was high and would be effective in encouraging people to recycle. People were concerned about the logistics of recycling and would recycle more if it involved less preparation of the materials. These findings support the idea that the public both wanted and needed more information about recycling benefits and about the logistics of recycling. Thus, campaigns designed to increase the participation of the targeted people should reinforce the existing altruistic motives of persons who are practicing conservation behaviors and should impact the motives, attitudes, and beliefs of persons who do not. Availability of sufficient information and exposure to actual programs can positively impact the public's attitudes toward MSWM plans. Further, the easy access to appropriate community infrastructure influences people's attitudes and motives.

*Improper organizational and technical approach*

Providing convenient organizational and technical structures for collecting and treating waste is must in order to create successful solutions. People expressed in discussions and through criteria mapping that easy and user-friendly system were important if they were to use those systems in a proper way. This was also pointed out by Barr et al. (2001), who argued that the main influences on recycling behavior are the logistics of recycling, especially the convenience of curbside schemes, and knowledge about recycling. Similar findings were made by Sidique et al. (2010), who found that the beliefs about recycling convenience, familiarity with recycling infrastructure and social pressure are significant drivers of recycling behavior. Recyclers tend to use the drop-off sites more, when they feel that recycling is a convenient activity and are familiar with the available recycling facilities. Hence, communication and education efforts aimed at improving awareness of recycling facilities and recycling convenience can be effective in promoting visits to recycling centers. They also found that leveraging social norms can enhance conservation (Schultz, 1999; Chen et al., 2009). However, despite the existence of the curbside recycling scheme there can still be a significant percentage of residents non-participating. McDonald and Oates (2003) recommended that mechanisms for joining the MSWM scheme also need to be publicized, possibly in local media or occasional leafleting, to attract tenants/owners. They found out that the design and the color of the recycling bin can be a deterrent enough for the people to participate. They also found out, people cited a "lack of paper" as their reason for non-participation in the MSWM scheme indicating that householders' perceptions of what is recyclable and how much paper is 'sufficient' to warrant recycling, might be misleading. This finding corroborates Tucker's (1999) result that householders believe curbside schemes are of little use to low consumers of newspapers.

*Situation in the developing world*

Huge disparity exists between MSWM researches in developed countries versus developing countries. Studies in the developed countries focus primarily on technical applications such as models and tools, policy analysis, socio-psychological, socio-economic influences on human behavior. However, research on MSWM in the developing world places more emphasis on the practical, direct factors influencing the institutions and elements associated with MSWM. Not much work has been done in understanding the indirect motives of one's behavior (i.e., recycling research focus in developed countries), though a couple of studies (such as Corral-Verdugo, 1997, 2003; Li, 2003) have been performed that seem to be on the lines and issues similar to that in the developed nations. During a study of reuse and recycling behavior in Mexico, Corral-Verdugo (1997) observed that competencies were the best predictors of actual behavior, whereas beliefs were more indicative of perception of behavior or desired behavior. In the case of recycling, one was more likely to recycle waste when fully understanding the proper way and the reasons to do it as opposed to one simply desiring to recycle. In another recent research Corral-Verdugo (2003) mentions, that reuse and recycling are mostly determined by facilitating situations and economic factors (which presumably also function as facilitators of conservation). Scientific information and news on communication media instigate waste control practices, but some commercial programs inhibit such practices. Finally, motives for reuse and recycling are also important determinants of waste control practices. Although some of those motives are also economic, many respondents see environmental preservation as an important reason for reuse and recycling, which offers some hope for the development of intervention programs. These programs should emphasize educational and social aspects, including provision of environmental procedural information, attitudinal change, participation, social and economic support and pro-environmental competency.

In a study of recycling behavior in Wuhan, China's fifth largest city, Li (2003) found that gender, age, and household income were three factors most influential to the activity of recycling. Particularly, elderly females responsible for the household duties of low-income families were most likely to recycle (Li, 2003). In exploring the relationship between environmental knowledge and action, factors influencing environmental behavior, and the ways to motivate environmental attitudes and behavior, Harvie and Jaques (2003) learned that residents of China possess greater knowledge of environmental issues and are more willing to participate in activities like recycling than US citizens (Harvie and Jaques, 2003).

*Inadequate MSW disposal management*

Inappropriate disposal of MSW, especially in developing countries, poses severe environmental and health threats. Environmental degradation such as underground water pollution, surface water pollution, air pollution and soil pollution occurs. Health impacts such as increase in the incidences of the diseases, impaired health due to increased exposure to pathogens, breathing problems and death may occur. . The U.S. Public Health Service identified 22 human diseases that are linked to improper solid waste management (Hanks, 1967. Cited in Tchobanoglous et al., 1993). Waste workers and pickers in developing countries are seldom protected from direct contact and injury; and the co-disposal of hazardous and medical wastes with municipal wastes poses serious health threat. An increase in the research and development in the efficacious disposal techniques is being underway, through out the world, to curb the menace caused by the improper disposal of the solid wastes. The following table 2.4.4 delineates some emerging techniques of the solid waste disposal. The emerging solid waste disposal technologies promise environmental, social and economic benefits if used satisfactorily. The environmental and social benefits of using these types of new technology are obvious. First, it dramatically improves the current condition of municipal and medical waste treatment. Second, it turns municipal waste into an energy resource. Third, it forms a new type of industry, pushing relevant industries forward, and adding employment opportunities. Fourth, it relieves traffic congestion and environmental pollution caused when transporting waste. Moreover, it improves the energy situation in towns and villages and the quality of life and reduces over all environmental pollution.

**Table 2.4.4: Emerging solid waste disposal techniques**

| S.No. | Solid waste disposal techniques | Type of waste | Reference(s) |
|---|---|---|---|
| 1. | New Pyrolysis Technology | MSW and Health care waste | Yufeng et al. (2003) |
| 2. | Dranco (Dry Anaerobic Composting) | MSW (Organic fraction) | Verma (2002) |
| 3. | Kompogas | MSW | Ahring (2003); Wellinger et al. (1993) |
| 4. | Anaerobic Landfillling | MSW and Industrial sludge | Ağdağ and Sponza (2007) |
| 5. | Geothermal disposal | Toxic solid waste | Premuzic et al. (1992) |
| 6. | Bio-drying | MSW | Dongqing et al. (2008) |
| 7. | Advanced Gasification | MSW | Morris and Waldheim (1998); Niessen (1996) |
| 8. | Bioreactor Landfilling | MSW | Blakey (1997); Benson et al. (2007) |
| 9. | Semi-aerobic Landfilling | MSW | Matsufuji et al. (2005) |

### *2.4.2 Hospital Waste Management (HWM)*

In the process of providing health-care to individuals waste is generated, which usually includes sharps, human tissues or body parts and other infectious materials (Baveja et al., 2000), also referred to as "Hospital Solid Waste" and "Bio-medical Solid Waste" (Manohar et al., 1998). The World Health Organization (WHO, 2000) defines hospital solid waste as any solid waste that is generated in the diagnosis, treatment or immunization of human beings or animals, in research pertaining thereto, or testing of biological, including but not limited to: soiled or blood soaked bandages, culture dishes and other glassware. It also includes: discarded surgical gloves and instruments, needles, lacents, cultures, stocks and swabs used to inoculate cultures and removed body organs.

The Government of India (Notification, 1998) specifies that hospital waste management is part of hospital hygiene and maintenance activities. This involves management of a range of activities, which are mainly engineering functions, such as collection, transportation, operation/treatment of processing systems, and disposal of waste. However, initial segregation and storage activities are the direct responsibility of nursing personnel, who are engaged in the hospital. There is a high potential of general non-infectious waste, becoming potentially infectious if the infectious components of the bio-medical waste (BMW) get mixed. Before the notification of Bio-Medical Solid Waste (Management and Handling) Rules 1998, the waste from the hospitals was the responsibility of municipal or governmental authorities, but now it has become mandatory for hospitals, clinics, other medical institutions and veterinary institutions to dispose of bio-medical solid waste as per the regulations. The onus lies on hospitals and other health-care institutions to ensure that there are no adverse health and environmental consequences as a result of their waste handling, treatment and disposal activities.

Medical waste generally consists of many different types of materials. While the relative proportion of the components of medical wastes produced from hospitals depends upon the types of health-care facilities (HCFs), the management practices of waste (e.g. handling, segregation and disposal), and the regulations of waste, as a whole; the major components of medical waste include tissues, single-use disposable plastics, absorbent cottons, and pathological wastes (Jang et al., 2006). The generation of hospital waste differs not only among the countries, but also within the same country by type of establishment, proportion of reusable items used and proportion treated on an out patient basis. A report published by WHO (1999), indicates that the generation of hospital waste is directly proportional to the income level, similar to the trend of MSW generation. Table 2.4.5 represents the range of hospital waste generation rates among the countries. It is reported that the range of values for countries of similar income levels probably is as wide in high-income countries as in less wealthy countries (WHO, 1999).

**Table 2.4.5: Hospital waste generation in various countries**

| Country | Generation rate (kg/bed/day) | Reference(s) | GNP/capita ($) |
|---|---|---|---|
| Tanzania | 0.84 | Mato and Kassenga (1997) | 320 |
| India | 1.6 | Patil and Shekdar (2001) | 724 |
| Iran | 1.25 | Askarian et al. (2004) | 2771 |
| Thailand | 1.75 | Adsavakulchai (2002) | 2940 |
| Japan | 2.05 | Tanaka et al. (2004) | 38,984 |
| Indonesia | 0.8 | Ananth et al. (2010) | 1,279 |
| Laos | 0.62 | Ananth et al. (2010) | 196 |
| Mongolia | 0.18 | Ananth et al. (2010) | 177 |
| Greece | 1.9 | Tsakona et al. (2007) | 19,687 |
| Italy | 3-5 | Madeira (1995) | 29,999 |
| USA | 5-7 | Medical Waste Committee (1994) | 43,743 |
| Portugal | 3.8<br>2.5-4.5 | Alvim Ferraz et al. (2000); Giroletti and Lodola (1994) | 16,164 |
| Jordan | 0.61-3.49<br>1.4 tons/day | Abdulla et al. (2008);<br>Bdour et al. (2007) | 2,426 |
| Philippines | 0.88 | Diaz et al. (2008) | 1,304 |
| Croatia | 1.2 | Marinković et al. (2008) | 8,064 |

BMW should be considered as a reservoir of pathogenic microorganisms and must be disinfected before disposal, since it is contaminated with microbial flora. If waste is inadequately managed these microorganisms can be transmitted by direct contact, in the air or by a variety of vectors, and can pose a serious threat to human health and to the environment. The inefficient handling of bio-medical waste is more likely to cause problems such as blood borne pathogens to the groups at highest risk, namely; health-care staff, scavengers, and municipal workers (Soliman and Ahmed, 2007). Solid BMW in any urban locality is approximately 1% of total MSW. But if containment and source separation are not practiced, then the BMW may get mixed with other MSW, rendering all of the waste infectious by microbial proliferation (Verma et al., 2008). As the incidence of HIV infection is on the rise, its incidence in the health-care environment is likely to be higher, resulting in enhanced risks and exposure to the health-care providers and waste handlers (Becker et al., 1989). A comparison of the MSW and hospital generation rates is provided in the table below.

**Table 2.4.6: Comparison of hospital and MSW generation rates in some countries**

| Country | Generation of hospital waste | Generation of MSW | Reference(s) | GNP / capita ($) |
|---|---|---|---|---|
| Vietnam | 1.16 kg/patient/day | 1.8* million tons/annum | Diaz et al. (2008) | 623 |
| Ecuador | 0.38-0.64 kg/patient/day | | Diaz et al. (2008) | 2,628 |
| China | 650,000 tons/day | 212 million tons /annum | Yang et al. (2009); Zhang et al. (2010) | 1,736 |
| Malaysia | 20,000 tons/ day | 7.9* million tons /annum | Ananth et al. (2010); Manaf et al. (2009) | 4,963 |
| United Kingdom | 33,000 tons/year 384.698 tons/year | | Blenkharn (2008); Woolridge (2005) | 37,632 |
| Macedonia | 14,600 tons/year | 1.2 million tons/annum | Hristovski (2007); Karagiannidis (2010) | 2,826 |
| Korea | 33,980 tons/year | 8.9* million tons /annum | Jang et al. (2006) | 10,975 |

*Calculated based upon the generation rates reported by World Bank (1999)

*Disposal of bio-medical waste*

Treatment by incineration and disposal of the resultant ash by landfilling is the most widely used treatment process for managing medical waste. The main disadvantage of medical waste incineration is the emission of pollutants to the atmosphere, some of them extremely toxic. Pollutants are usually emitted either in condensed (particulate matter) or in gaseous phases. Many organic and metallic compounds have known effects on human health and environment (Ficarella and Laforgia, 2000; Wang et al., 2002).

According to Alvim-Ferraz and Afonso (2003), research works showed that without control of atmospheric pollutants, the incineration of medical waste does not obey the legal emission limits, even when correct practices of operation and maintenance are used (controlled feeding rate, controlled combustion air, high temperatures, proper turbulence and residence time) (Alvim Ferraz et al., 2000; Coutinho et al., 2000). Thus, to protect public health, hospital incinerators should be provided with air pollution control devices in order to reduce pollutant concentrations to levels even lower than the legal ones. As most hospital incinerators do not possess such equipment, efficient methodologies should be developed in order to evaluate the safety of incineration procedure, through the comparison with legal limits.

Since the promulgation of the Bio-Medical Solid Waste (Management and Handling) Rules 1998, it is the duty of the health-care facilities such as hospitals, clinics etc to manage and dispose the infectious waste innocuously, major disposal option of medical waste from most health-care facilities is to pay a licensed–private transporter to transport the waste to a medical waste to a common or large incineration facility or common bio-medical waste treatment facility (CBWTF) provided by the Government of India at various important locations throughout the country. It is the most common method of medical waste disposal is off-site treatment, which accounts for approximately 61.5% of the total waste stream. The rest of the waste is disposed off as follows (Verma et al., 2008):

1. discarding the waste into the municipal sewer (46.6%),
2. depositing in landfills (41.6%), and
3. autoclaving (32.3%).

*Transportation of the bio-medical waste*

The cost of collection and transportation generally constitutes 80–95% of the total budget of solid waste management; hence it forms the key component in determining the economics of the whole waste management system (Shih and Chang, 2001). Besides other factors, collection and transportation time, routing, the design and carrying capacity of vehicles and types of bins have a significant effect on the efficiency of the waste management system.

Though some of the major HCFs are treating the infectious waste by on-site incinerators or steam sterilization facilities at some general hospitals where incinerators or steam sterilization is available, small HCFs may not be in a position to install required equipment on their premises. It may therefore be appropriate for small HCFs to outsource waste management, handling and disposal. However, a study conducted at University of Chicago (Anonymous, 2002) confirms that outsourcing may not be cost effective for larger HCFs, and on-site treatment of infectious waste may be less costly. This makes the selection of appropriate bio-medical waste handling contractors, especially for the small and medium health-care facilities, difficult owing to the number of safeguards such as:

- availability of proper equipment
- proper treatment
- regular maintenance
- regular cleaning of vehicles
- safety precautions for the waste handlers
- transportation schedules
- emergency procedures
- safety to public at large while transporting the waste on roads and
- safety and risk prevention during transportation

*Recent trends in bio-medical waste disposal*

BMW management carried out by the use incinerators is on the decline (USEPA, 2002). Public concern about the environmental and health impacts of incineration has made this disposal option even more costly and difficult to undertake. Public resistance to incineration is so great that no new incinerators have been built in recent years, and expansions or upgrades to existing incinerators are difficult to get approved (Bastian 1997). In 1999, the Philippines became the first country to ban burning of all waste, including biomedical waste (HCWH, 2004). Incinerators are considered a polluting option; polluting to the air as well as to the groundwater, when wash water from scrubber/air pollution control units containing chemical wastes is discharged into the sewer or sent to an unsecured landfill. Emissions from incinerators may contain chemical pollutants, which can settle on the ground (foliage), thus entering the food chain. In the USA, 70% of all dioxin release to the air is from combustion sources (GAIA, 2000). With the use of incinerators on the decline, many non-burn technologies have been developed, commonly known as 'alternate technologies'. In fact, a whole array of industries are manufacturing alternate technologies, such as autoclave, microwave, hydroclave (or similar equipment), or combinations. The following Table 2.4.7 gives a brief view of the new disposal techniques for the HCW such as sharps, cultures and stocks, items contaminated with blood, liquid human and animal wastes, residues from surgery and from isolation wards, bandages, gauze, linen, gowns, and other similar materials and non-chemical laboratory wastes.

**Table 2.4.7: Some recent disposal technologies for health-care waste**

| Technology | Description | References |
|---|---|---|
| Autoclave & Retort | Hermetically sealed metal vessel used to treat HCW, in bathes, through steam in a high vacuum. | Diaz et al. (2005);Reinhardt and Gordon (1999); US Congress (1990) |
| Microwave | Shredded HCW, in presence of moisture, is treated through microwaves at temperature of $95^0$ C-$100^0$C. The steam generated disinfects the HCW. | Diaz et al. (2005);Reinhardt and Gordon (1999); US Congress (1990) |
| Chemical disinfection | Appropriate chemical agent is used to inactivate pathological organisms. The effectiveness of a certain chemical agent depends upon temperature, pH, and on the possible presence of other compounds, which can have a negative impact on the effectiveness of the chemical agent. | Diaz et al. (2005);Reinhardt and Gordon (1999); US Congress (1990) |
| Combustion | Combustion of HCW under controlled conditions, using equipment that operates at temperatures on the order of $900^0$C–$1000^0$C, and that includes air pollution control equipment as well as other components to manage the emissions from the unit. | Diaz et al. (2005) |
| Encapsulation | Used dispose of sharps generated by large immunization programs in a lined pit with impermeable material such as clay or membrane. The pit is 2-3 m deep and above 1.5 m above the depth of the ground water. Once the pit is filled with the sharps a cement mixture is added to encapsulate the waste and the pit is closed. | Diaz et al. (2005) |
| Plasma | A 100-150 kW heat source is used to generate arc plasma, generally using argon for ignition. After ignition the air is used for treating HCW and bottom ash from hospital incinerators. The processing is for 15-30 min at a temperature of $1550^0$C-$1600^0$C | Cedzynska (1999); Chu et al. (1998); Nema, and Ganeshprasad (2002); |

## 2.5 ENVIRONMENTAL IMPACTS

The environmental impacts of the improper dumping have been discussed before in section 2.4.1. However, there are still some environmental impacts even if the MSW or hospital/infectious waste is disposed off with the help of the scientific technology; the impacts vary with each kind of technology put to use.

*Landfilling:* The environmental impacts of landfilling the waste are largely dependent upon the land fill design, daily operation and the kind of solid waste being disposed. The major concerns of landfilling are the impacts due to the landfill gas (LFG) and the leachate generated. The potential impacts of LFG are:

- Explosions-due to inadequate capture and accumulation of the LFG, which is rich in Methane and other explosive gases
- Flash fires
- Asphyxiation- of fauna and people that are in frequent contact of the landfill site.
- Nuisance- odors emanating from the landfill
- Visual impacts
- Noise- due to the continuous tipping of trucks, gas collection system and use of compressors
- Water Pollution
- Corrosion of equipment

*Waste Incineration:* The combustion of MSW under controlled conditions, aims to reduce the volume of the waste generated and thereby providing significant savings in transport costs and landfilling. It destroys the organic, putresceble fraction of the waste, thus eliminating the possibility of landfill gas and leachate generation. The process of incineration is highly controversial owing to high investments in controlling emissions of the pollutants in the environment (Tchobanoglous, 1993). Not only this, a large space is required as well to house the incineration building and associated storage facilities, as it is vital to achieve an efficient flow of waste into and out of storage area and smooth disposal of incineration ashes too ( Daskalopoulos et al., 1997). Incineration of solid waste too impacts the environment in the following way:

- Pollutant emissions to the atmosphere
- Contaminated waste water
- Contaminated ash with concentrated pollutants
- Odor, litter, dust
- The pyrolysis products arising form the decomposition of waste may be combusted incompletely, so resulting in the emission of the carbon monoxide, volatile organic compounds such as polyaromatic hydrocarbons, dioxins and furans, tar and soot particles
- Particulate emissions
- Heavy metals release

Incinerations are being installed due to:

- Concern over direct landfilling of materials such as health-care wastes, and identification of problem wastes for which incineration represents the only commercially available method of disposal
- Legislative controls curtailing other disposal routes (such as sewage sludge)
- Contamination of soils necessitating bioremediation and
- Energy generation potential

*Composting:* The biological decomposition and stabilization of organic fraction of the solid wastes under conditions that encourage thermophillic temperatures, as a result of the bio-chemical reactions is known as composting. The product, compost, produced is reused to accomplish several purposes like reclaiming the nutritive value of the soil by providing nitrogen, phosphorus and other important trace elements, to provide necessary soil structure, moisture holding capacity and organic matter to the soil. The major environmental impacts due to the composting of solid waste are majorly, deteriorating waster and air quality apart from a potential threat to public health as it attracts vectors and rodents.

*Recycling:* Recycling is defined by Marowski (1992) as using materials, which are at the end of their useful lives; for feeding stocks in the manufacturing of new products. Recycling differs from re-use because it involves processing; it differs from resource recovery, since in resource recovery, materials are recovered for reuse from a mixed stream of solid waste.

Recycling is often described as the collection of materials separated from the waste. This operation is more correctly defined as reclamation (Daskalopoulos, 1997). The environmental impacts of recycling include avoiding operational and external costs associated with waste disposal (i.e. costs of environmental damage by leachate, emissions in the air etc) and the possible revenue from the dale of the recycled materials. The benefits are counter-balanced by costs such as costs incurred due to the separation of used materials from mixed waste, costs associated with any process involved (e.g. cleaning, de-inking and re-melting) and any external costs (e.g. costs of environmental pollution from de-inking processes and health risks from the sorting and recycling processes). There are varieties of environmental justifications for recycling:

- The conservation of the finite resources , enabling sustainability
- Reduction in energy consumption for production
- Limiting pollutant emissions
- Environmental education benefits from participation in recycling.

## 2.6 APPLICATION OF THE MCDM TECHNIQUES

Environmental decision making is particularly affected by limits to foresight. For example, at a local level, decisions regarding the long-term management of solid waste depend, in part, upon future population, rates of waste generation per capita, recycling rates per capita, and with respect to the financial viability of recycling programs, the market prices for recycled materials such as paper and aluminum. One could argue that one's crystal ball would probably be much clearer with respect to population changes in the community that it would be with respect to market prices for recycled materials. The problems addressed herein are how to gauge the limits to foresight for variables such as these and then how to relate different limits to foresight profiles to appropriate decision-making strategies (Tonn and Peretz 2001).

Municipal solid waste is just one of many environmental decision-making problems that could benefit from these methods. Knowledge-based system techniques such as MCDM may be used to provide advice and therefore, an increased level of support in the solid waste management and planning field (Thomas et al. 1990). Several characteristics of the problem domain of MSW management and planning make it suitable for the investigation of knowledge-based system techniques: due to the complexity and uncertainty involved, few individuals exist that would have expertise in all aspects of an integrated waste management system; judgment and expertise is required to make management and planning decisions; and many qualitative issues are involved. Waste management professionals may benefit from the permanent collection of expertise in the knowledge bases, and the provision of a framework for investigating problems. In addition, knowledge-based system components may allow the mathematical models to be more user-friendly and understandable, potentially extending their usage as an aid to decision-making.

The potential users of the MCDM techniques or decision support system would be consulting engineers, waste management engineers, recycling coordinators, municipal managers and decision-makers. The structure of the decision support system should permit the knowledge based system components to be clearly understood and thus easily modified, due to the constantly expanding expertise, varying economic, social and technological environments in this field.

# CHAPTER 3

# PRIORITIZING SOLID WASTE MANAGEMENT FACTORS USING FUZZY ANALYTIC HIERARCHY PROCESS

## 3.1 INTRODUCTION

Municipal waste quantities across India continue to grow along with the burgeoning population. In order to serve better, the Indian government in association with local authorities is making efforts to manage the solid waste generated in a way that is not only innocuous to the environment but also acceptable to the people. The local authorities are drawing up municipal solid waste management (MSWM) plans with the help of experts and inputs from the local population. Though the plans are being formulated in various parts of the country, still there are problems in achieving the effective MSWM for an area (Singhal and Pandey, 2001).

For effective MSWM the various factors that are taken in consideration while formulating a scheme should be identified correctly and should be given due importance for the plan to be a success. Otherwise, the most inventive schemes also turn useless. The primary measure of success of a designed scheme is the degree to which it meets the purpose for which it is intended (Khan et al., 2008). People satisfaction is commonly acknowledged as one of the useful proxy measures of MSWM success. Hence, it is essential to identify MSWM factors for setting satisfactory system standards.

---

*A part of this chapter has been accepted for publication as:*

*'Prioritizing Municipal Solid Waste Management Factors in India using Fuzzy Analytic Hierarchy Process'* ***International Journal of Environment and Waste Management*** *(Inderscience Publication)*

Motivated by these points, the objective of this chapter is to propose an analytic framework to prioritize various MSWM factors so that an efficient MSWM scheme could be formulated. The proposed framework consists of three main steps:

1. Identifying MSWM factors
2. Structuring MSWM factors and
3. Identifying the importance weights for MSWM factors.

Determining the correct importance of the MSWM factors is essential for an efficacious solid waste management (SWM) scheme. Various methods have been attempted to determine the importance of weights. The simplest method to prioritize is based on a point scoring scale, such as one to five or one to ten. However, this method cannot effectively capture human perception. Prioritizing MSWM factors can be viewed as a complex multi-criteria decision-making (MCDM) problem as SWM is an amalgamation of various factors such as political, socio-cultural, technical, fiscal, and environmental factors (Khan and Faisal, 2008). The analytic hierarchy process (AHP), a MCDM method can be used for the prioritizing the factors. But conventional AHP seems inadequate to explicitly capture the importance assessment for MSWM factors since it is recognized that human assessment on multiple and qualitative attributes is always subjective and imprecise. Though the use of the discrete scale of 1–9 in conventional AHP is easier to represent the verbal judgment, but it doesn't take into account the uncertainty associated with the mapping of one's perception or judgment to a number. In real-life decision-making situation, the decision makers could be uncertain about their own level of preference, due to incomplete information or knowledge, complexity and uncertainty within the decision environment (Promentilla et al., 2008). Therefore, in this chapter, the linguistic assessment of MSWM factors has been converted to triangular fuzzy numbers (TFNs). The triangular fuzzy numbers are used to build a pairwise comparison matrix for AHP (Boender et al., 1989). By applying fuzzy AHP methodology an attempt has been made to obtain the importance of weights of MSWM factors.

Many cities in India face serious environmental degradation and health risks as piles of infectious waste are dumped along with the municipal waste. With the augmentation in number of diseases like AIDS and Hepatitis B and C, it has come to attention of the public that the clinic near them may be nurturing something dangerous. Hospital or infectious waste in particular is a reservoir of pathogens. If it is inadequately managed, it may give rise to infections and various diseases through direct contact or by a variety of vectors. Moreover, the health-care establishments are situated in the very heart of the cities and therefore pose a potential threat to the public in general.

Uncollected dumping of medical waste poses threat to not only the surrounding environment but also to the person handling it. Some medical items such as disposable syringes, used bandages, surgical gloves, blood bags, catheters and intravenous tubes etc find there way again in the market as they are being washed and re–packaged. With such aggravating situation the Government of India has framed Bio-Medical Waste (Management and Handling) Rules1998 making it mandatory for health-care facilities (HCFs) to properly dispose bio-medical waste. However, the institutions do not comply with the rules and the conditions within them are pathetic. Therefore, there is urgent need to improve upon the medical waste management practice. Hence, systematic and planned approach to deal with the infectious or bio-medical waste is required to guide the hospital management in particular towards better medical waste management practice. Generally, the small and medium sized hospitals outsource the collection, handling and transportation of the bio-medical or infectious waste to an agency or a contractor for disposal at a common waste treatment facility, set up by the government at different locations throughout the country.

For effective infectious waste management the various factors that are taken in consideration, while appointing a contractor should be identified correctly and should be given due importance for achieving the target of innocuous disposal of the BMW. Hence, it is essential to identify infectious waste management factors for setting satisfactory system standards.

The idea of appointing a contractor on a scientific basis prompted this research to prioritize the various factors. Therefore, another model with this objective is introduced in the chapter. The second model proposes an analytic framework to prioritize various infectious waste factors so that an efficient and best possible contractor could be selected. The proposed framework consists of three main steps:

1. Identifying infectious waste management factors for selection of contractors
2. Structuring these infectious waste management factors and

3. Identifying the importance weights for the factors.

Determining the correct importance of the infectious waste management factors is essential for selection of best possible contractor. Various methods have been attempted to determine the importance of weights. As the contractors handling bio-medical waste is a complex problem, a similar approach to the model on MSWM prioritization factors has been adopted. The factors for the selection of contractor are prioritized using multi-criteria decision-making (MCDM) methodology, since it is a combination of various factors such as their capability, qualification etc. Thus, here fuzzy analytic hierarchy process (AHP), has been used with triangular fuzzy numbers.

The chapter is organized as follows: Section 3.2 presents the method used that is fuzzy AHP, to compute the weights of the factors. A brief literature review about the proposed methodology is given in section 3.3. Section 3.4 illustrates the MSWM factors to be prioritized in designing of any MSWM plan. Section 3.5 gives a discussion on the results obtained from the application of the model. Section 3.6 consists of the model development for the infectious waste factors prioritization for the selection of contractors. The model development includes identification of factors followed by the application of the proposed framework giving the analytic results obtained. Discussion on the model follows in the section 3.7. Conclusions about the results obtained for the two models are given in the section 3.8. The last section of the chapter is about limitations and scope for future research.

## 3.2 FUZZY AHP MEHTODOLOGY

Despite of its wide range of applications, the conventional AHP approach may not fully reflect a style of human thinking. One reason is that decision-makers usually feel more confident to give interval judgments rather than expressing their judgments in the form of single numeric values. As a result, fuzzy AHP and its extensions are developed to solve alternative selection and justification problems. Although fuzzy AHP requires monotonous computations, it is capable of capturing a human's appraisal of ambiguity, when complex multi-attribute decision-making problems are considered. For details on the use of AHP and its various calculations, the reader is referred to the work of Saaty (1980). Chang (1992; 1996) developed a fuzzy extent analysis for AHP, which has similar steps as that of Saaty's crisp AHP. However, his approach is relatively easier in computation than the other fuzzy AHP approaches. In this chapter, we make use of Chang's fuzzy extent analysis for AHP.

A fuzzy number is a special fuzzy set $F=\{x\in R|\mu_F(x)\}$, where x takes its values on the real line $R_l$: $-\infty<x<+\infty$ and $\mu_F(x)$ is a continuous mapping from $R_l$ to the close interval [0, 1]. A triangular fuzzy number can be denoted as $M=(l, m, u)$. Its membership function $\mu_M(x)$: $R \rightarrow [0, 1]$ is equal to:

$$\mu_M(x) = \begin{cases} 0, & x<l \text{ or } x>u, \\ (x-l)/(m-l), & l\le x\le m, \\ (x-u)/(m-u), & m\le x\le u \end{cases} \quad (1)$$

Where $l\le m \le u$, $l$ and $u$ stand for the lower and upper value of the support of M, respectively, and $m$ is the mid-value of M. When $l=m=u$, it is a non-fuzzy number by convention. The main operational laws for two triangular fuzzy numbers $M_1$ and $M_2$ are as follows (Kauffman and Gupta, 1991):

$$\begin{aligned} &M_1+M_2=(l_1+l_2, m_1+m_2, u_1+u_2), \\ &M_1\otimes M_2\approx(l_1l_2, m_1m_2, u_1u_2), \\ &\lambda\otimes M_1=(\lambda l_1, \lambda m_1, \lambda u_1), \lambda>0, \lambda\in R \\ &M_1^{-1}\approx(1/u_1, 1/m_1, 1/l_1) \end{aligned} \quad (2)$$

Let $X=\{x_1, x_2 \ldots x_n\}$ be an object set, and $U=\{u_1, u_2 \ldots u_m\}$ be a goal set. According to the method of Chang's extent analysis model, each object is taken and extent analysis for each goal, $g_i$, is performed respectively (Chang, 1992; 1996). Therefore, $m$ extent analysis values for each object can be obtained with the following signs:

$$M_{gi}^1, M_{gi}^2, \ldots\ldots\ldots, M_{gi}^m, i=1,2,\ldots\ldots\ldots, n \quad (3)$$

Where all the $M_{gi}^j (j=1,2,\ldots\ldots m)$ are triangular fuzzy numbers. A triangular fuzzy number can be denoted as $M=(l, m, u)$ where $l\le m\le u$, $l$ *and* $u$ stand for the lower and upper value of the support of M, respectively, and $m$ is the mid-value of M.

The steps of the improved Chang's extent analysis model, which is applied in this study, can be given as follows:

***Step 1:*** The value of fuzzy synthetic extent with respect to the $i$th object is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \tag{4}$$

To obtain $\sum_{j=1}^{m} M_{gi}^{j}$, perform the fuzzy addition operation of *m* extent analysis values for a particular matrix such that

$$\sum_{j=1}^{m} M_{gi}^{j} = \left( \sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{5}$$

and to obtain $\left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$, perform the fuzzy addition operation of $M_{gi}^{j}$ ($j$= 1, 2, .....$m$) values such that

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left( \sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \tag{6}$$

and then compute the inverse of the vector in Eq. (6) such that

$$\left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left( \frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \tag{7}$$

The principles for the comparison of fuzzy numbers were introduced to derive the weight vectors of all elements for each level of the hierarchy with the use of fuzzy synthetic values. We now discuss these principles that allow the comparison of fuzzy numbers (Zhu et al., 1999).

***Step 2:*** The degree of possibility of $M_2 \geq M_1$ is defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x} [\min(\mu_{M1}(x), \mu_{M2}(y))] \tag{8}$$

When a pair (x,y) exists such that $y \geq x$ and $\mu M_1(x), \mu M_2(y)$, then we have $V(M_2 \geq M_1)=1$. Since $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are convex fuzzy number we have that

$V(M_2 \geq M_1) = \text{height}(M_1 \cap M_2) = \mu_{M2}(d)$

$$\begin{cases} 1, if\ m_2 \geq m_1 \\ 0, if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_1 - u_2) - (m_1 - l_1)}, & \text{otherwise} \end{cases} \tag{9}$$

Where $d$ is the crossover point's abscissa of $M_1$ and $M_2$. To compare $M_1$ and $M_2$, we need both the values of V ($M_1 \geq M_2$) and V ($M_2 \geq M_1$).

***Step 3:*** The degree of possibility for a convex fuzzy number to be greater than $k$ convex fuzzy numbers $M_i$ (i=1, 2,......$k$) can be defined by

$$V\,(M \geq M_1, M_2, \ldots\ldots M_k)$$

$$= V\,[(M \geq M_1) \text{ and } M \geq M_2) \text{ and } \ldots\ldots (M \geq M_k)] \tag{10}$$

$$= \min V\,(M \geq M_i),\ i = 1, 2, 3, \ldots, k$$

Assume that

$$d'(A_i) = \min V(S_i \geq S_k) \tag{11}$$

for $k=1,2,....n;\ k \neq i$. Then the weight vector is obtained as follows:

$$W' = (d'(A_1), d'(A_2), \ldots\ldots\ldots\ldots, d'(A_n))^T \tag{12}$$

Where $A_i$ $(i=1, 2, \ldots\ldots\ldots, n)$ are $n$ elements.

***Step 4:*** After normalization, the normalized weight vectors are,

$$W = (d(A_1), d(A_2), \ldots\ldots\ldots\ldots, d(A_n))^T \tag{13}$$

Where $W$ is non-fuzzy number.

In recent times AHP method is applied to deal with several issues in the area of civil and environmental engineering; e.g., Khasnabis et al. (2002), Uddameri (2003), Dey (2002), McIntyre et al. (1999), Ock et al. (2005), Ziara et al. (2002), etc. In the area of environmental engineering fuzzy-AHP is used by researchers like Tesfamariam and Sadiq (2006) and Sadiq and Tesfamariam (2009). The AHP uses objective mathematics to process the subjective and personal preferences of an individual or a group in decision making (Saaty, 2001). AHP helps the decision maker to manage complicated problem by converting it into manageable and comprehensible small problems. However, conventional AHP did not truly reflect human cognitive processes, especially in the context of problems that were not fully defined and/or problems involving uncertain data (so-called "fuzzy" problems) (Fu et al., 2006).

In solving various real-world decision situations, it is necessary to handle uncertainties efficiently and effectively. There may be several reasons for uncertainty in a decision-making situation. Some of the reasons are problem complexity, ill-posed questions, imprecision in computations, ambiguity in data/knowledge representation, problems in input interpretations, and noise (Keller and Tahani, 1992). Vagueness type uncertainties can be handled using the fuzzy set theory (Zadeh, 1965). Fuzzy reasoning and logic offers a more natural way of handling uncertainty. All propositions can be modeled by possibility distributions over *appropriate domains. Fuzzy reasoning process is similar to human logical reasoning, and a* considerable amount of research work has been performed in this area (Takagi and Hayashi, 1991). So instead of using exact numbers as in conventional AHP, we can use phrases like "much more important than" to extract the decision makers preferences. Fuzzy logic and values offer a more natural way of dealing with these preferences instead of exact values (Murtaza, 2003).

In order to perform pairwise comparison among the factors and their attributes, a linguistic scale has been developed. The scale is depicted in Figure 3.1 and the corresponding explanations are given in Table 3.2.1. There are several ways to represent fuzzy numbers. Different shapes of fuzzy numbers are possible like bell, triangular, trapezoidal, Gaussian, etc. (Tesfamariam and Sadiq, 2006). One special class of fuzzy numbers is triangular fuzzy number, which is easy to model and works well with most applications (Murtaza, 2003). In this chapter, triangular fuzzy numbers (TFNs) are used. TFN is represented by three points (a, b, c) on the universe of discourse (scale X on which criterion is defined), representing the minimum, most likely, and maximum values, respectively. This scale is adapted from Büyüközkan (2009).

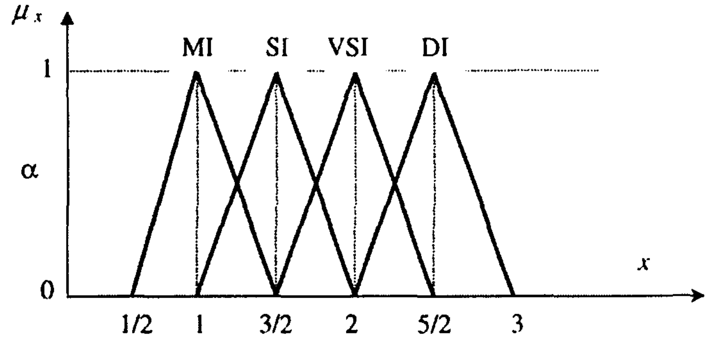


**Figure 3.1: Triangular fuzzy scale**

Figure 3.1 shows the triangular fuzzy numbers $M = (l, m, u)$ where $l \leq m \leq u$, $l$ and $u$ stand for lower and upper value of support for $M$, respectively and $m$ is the mid-value of $M$.

**Table 3.2.1: Triangular fuzzy importance scale**

| Linguistic scale | Explanation | Triangular fuzzy Scale | Triangular fuzzy reciprocal scale |
|---|---|---|---|
| Equal Importance (EI) | Two requirements are the same importance | (1,1,1) | (1,1,1) |
| Moderate Importance (MI) | Experience and judgment slightly favor one requirement over another | ( 1/2, 1, 3/2) | (2/3,1,2) |
| Strong Importance (SI) | Experience and judgment strongly favor one | (1, 3/2, 2) | (1/2, 2/3, 1) |
| Very Strong Importance (VSI) | A requirement is favored very strongly over another; its dominance demonstrated in practice | (3/2, 2, 5/2) | (2/5, 1/2, 2/3) |
| Demonstrated Importance (DI) | The evidence favoring one requirement over another is the highest possible order of affirmation | (2, 5/2, 3) | (1/3, 2/5, 1/2 ) |

## 3.3 LITERATURE REVIEW

Modeling of solid waste management is not a new idea. Gottinger (1988); Tanskanen (2000); and Morrissey and Browne (2004a) have given comprehensive summaries on the models for SWM spanning from the early 1960s to the 1990s. Table 3.3.2 lists some of the methods that have been developed to address SWM and related problems. The focus of the models varies from developing and optimizing collection routes and facility site selection, to developing sophisticated models with the aid of computers in the 1980s so that the cost of the mixed waste management is minimized (Gottinger, 1988). During the 1990s, recycling became a strategic norm in SWM planning models such as those developed by Smith and Baetz (1991). However, it was in the early 1990s that SWM modeling started recognizing SWM as an intrinsically complex problem, as it encompassed several objectives and difficulties that were often in conflict with each other. Thus, MCDM models like those developed by Caruso et al. (1993) started gaining recognition. In recent years, decision models based on life cycle analysis (LCA) and MCDM have become popular. Earlier models were developed for optimization, where models assumed that the different objectives of the proposal could be expressed by a common denominator or scale of measurement, whereby the loss in one objective could be directly evaluated against a gain in another (Morrissey and Browne, 2004a).

**Table 3.3.2: Various kinds of solid waste problems***

| Decision method | Decision problem | Reference(s) |
|---|---|---|
| Fuzzy analytic network program | Remedial countermeasure for contaminating landfills | Promentilla et al. (2008) |
| Fuzzy analytic hierarchy program | Decision-making for Municipal SWM (MSWM) Site screening for landfill | Hung et al. (2007)<br>Charnpratheep et al. (1997) |
| Analytic hierarchy program | Medical SWM<br>Sustainable development planning | Karamouz et al. (2007)<br>Quaddusa and Siddique (2001) |
| LCA and economic model | Efficient strategy for SWM | Emery et al. (2007) |
| Analytic network program | Remedial countermeasure for contaminating landfills | Promentilla et al. (2006) |
| Cost benefit analysis (NPV, etc.) | Waste disposal options<br>Assessment of SWM alternatives | Aye and Widjaya (2006)<br>Smith and Baetz (1991) |
| WASTED | Life Cycle Analysis (LCA) of SWM | Diaz and Warith (2006) |
| Ranking and weighted model | Environmental diagnosis of landfill sites | Calvo et al. (2005) |
| Stoichiometric model | LCA of Integrated SWM | Mastro and Mistretta (2004) |
| Mathematical model | Urban SWM (USWM)<br>Model for USWM | Costi et al. (2004)<br>Caruso et al. (1993) |
| Dynamic modeling | Assessing disposal demand for UMSW | Leao et al. (2001) |
| Static and linear simulation model | Analysis of recovery rates, costs and emissions of MSWM | Tanskanen (2000) |
| Grey fuzzy dynamic modeling | Forecasting SW generation | Chen and Chang (2000) |
| Computational model | Waste management and facility siting | Gottinger (1988) |

(* *Adapted from Khan and Faisal*, 2008)

Analytic hierarchy process (AHP) is widely used in environmental management field (such as Triantaphyllou et al., 1997; Partovi et al., 1990; Karamouz et al., 2007; Sadiq et al., 2005; Sadiq and Rodriguez, 2004). Many scholars have been taking research and practice to use AHP in the fields of project planning (such as Zhang and Zhong, 1995; Minehart, 2002; Wedding and Brown, 2007), environmental appraisal (such as Yinga et al., 2007; Juwen et al., 2007), risk appraisal (Sadiq and Rodriguez, 2004; Pusch, 1998) and engineering design (Jinbo, 1997). Qualitative analysis and quantitative analysis could be combined by AHP to *deal with the problems in multiple objective decisions. The fuzzy AHP is used in the research* about the technology, economy and society problems with complex factors and also used to setup priority list sometimes (Shi et al., 2008; Minglung et al., 2006; Yedla and Shrestha, 2003; Liu, 2003). Compare with other methods, fuzzy AHP is of more maneuverability, easier to setup index system and less in calculation.

## 3.4 MODEL FOR MUNICIAPL SOLID WASTE MANAGEMENT

### *3.4.1 Municipal solid waste factors*

To comprehensively identify the factors required for the formulation of MSWM scheme, a two step approach was adopted. Firstly, to identify the main factors review of SWM literature was done. Secondly, the factors were subjected to the examination and modification of MSWM experts in India. By this way finally 10 factors were retained in a grouped into three categories: environmental, economic and social. On the basis of the literature review, the information was summarized into a preliminary three-layer hierarchical structure of MSWM factors. This preliminary hierarchical structure was submitted to a panel of four academics and three experts from industry for review. The scholars were academics, who had conducted relevant research in this area for several years; the industrial experts were people, who had been directly involved in decision-making regarding municipal solid waste management and being particularly involved in one or other solid waste management project carried out by either state or central governments in India. This panel of scholars and experts deliberated on the appropriateness of relevant factors and finally converged on the most important factors (Table 3.4.3); for a short term plan of two to five years, which form the final three-layer hierarchical structure as represented in Figure 3.2.

**Table 3.4.3: Important municipal solid waste management factors**

| Factors | Description | Reference(s) |
|---|---|---|
| Amount of waste | The total amount waste that is generated in a given area where the scheme is to be implemented | Morrissey and Browne (2004b)<br>Cheng et al. (2003)<br>Tchobanoglous et al. (1993) |
| % Recycled | The amount of waste that is recycled from the total waste generated | Tchobanoglous et al. (1993)<br>Baetz et al. (1991) Thomas et al. (1990) |
| % Composted | The total amount of waste that is composted | Tchobanoglous et al. (1993)<br>Baetz et al. (1991) Thomas et al. (1990) |
| % Land filled | The percentage of the total amount of waste generated that is finally disposed in the landfill | Tchobanoglous et al., (1993)<br>Baetz et al., (1991) Thomas et al., (1990) |
| Cost of waste collected | The cost that is incurred on the primary and secondary collection of the waste generated | Cheng et al. (2003)<br>Tchobanoglous et al. (1993)<br>Thomas et al. (1990) |
| Cost of disposal | The cost incurred o the disposal of the waste that finally is land filled | Cheng et al. (2003)<br>Tchobanoglous et al. (1993)<br>Thomas et al. (1990) |
| O & M Cost | The cost that comes as a result of collection and disposal of waste while using compactors, trucks, loaders etc. | Cheng et al. (2003)<br>Tchobanoglous et al. (1993)<br>Thomas et al. (1990) |
| Population served | The total number of people that will be served from the scheme that is being formulated | Morrissey and Browne (2004b) |
| % of population involved in recycling and composting | The number of people from the total population served involved in the recycling and composting (backyard) of the waste | Morrissey and Browne, (2004b) |
| Employment rates | The increase in the employment of people due to the scheme of SWM | Morrissey and Browne (2004b)<br>Thomas et al. (1990) |

### *3.4.2 Importance of Weights for Municipal Solid Waste Factors*

As previously mentioned, in the next step of framework, the fuzzy AHP methodology is applied. For criteria weight determination the main MSWM factors along with the related attributes are given in Figure 3.2.

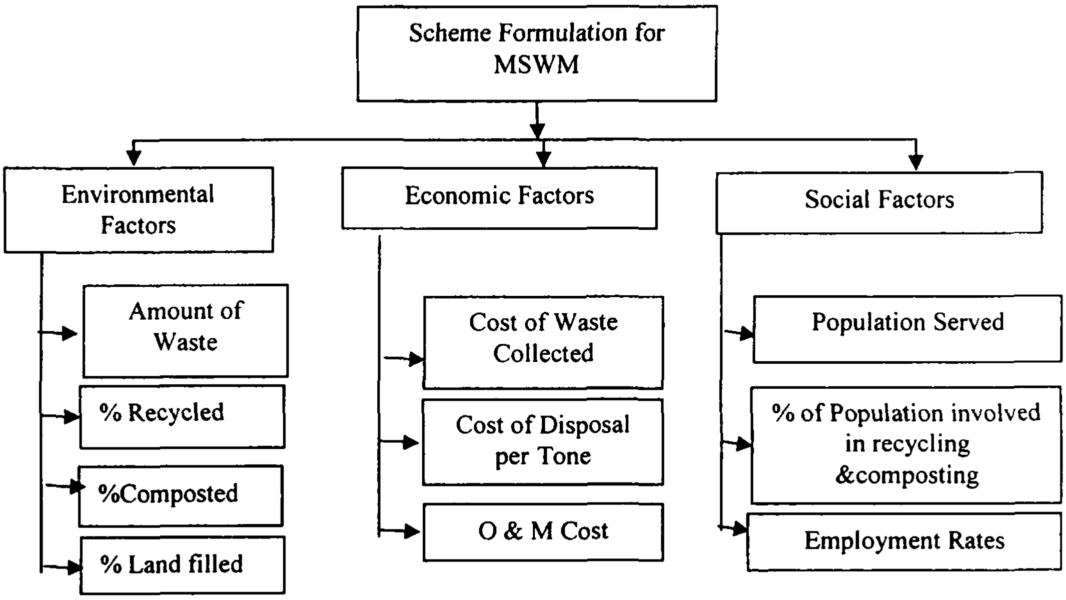


**Figure 3.2: Hierarchy model for the determination of MSWM factors**

In order to develop and evaluate fuzzy AHP model, a thorough literature review, informal discussions and questionnaire were provided to the officials of the municipality, academics, and experts working in the field of solid waste management were carried out. The questions in the MSW questionnaire mainly addressed the issues; in solid waste management; that are prevalent in Class 1 cities with a population of more than one million. A sample of questions from the MSW questionnaire is given in Table 3.4.4. The questionnaires were administered by two ways. First around 40 questionnaires were sent by post to the individuals or organizations who were involved in MSWM. Further, authors also contacted personally about 10 experts and collected the questionnaire from them. Out of these 10 experts, five were from academia and five from the industry. Majority of the experts and organizations covered in the questionnaire based study were based in northern India. In the mailed questionnaires around 23 were returned, indicating a response rate of more than fifty percent which is well accepted in questionnaire based studies.

**Table 3.4.4: Sample questions from the MSWM questionnaire**

Read the following questions and put check marks on the pairwise comparison matrices. If an attribute on the left is more important than the one matching on the right, put your check mark to the left of the "Equal importance" column, under the importance level (column) you prefer. On the other hand, if an attribute on the left is less important than the one matching on the right, put your check mark to the right of the importance "Equal Importance" column, under the importance level (column) you prefer.
With respect to the overall objective, evaluate the following MSWM factors
Q1. How important are environmental factors (ENV) when compared to economic factors (ECO)?
Q2. How important are economic factors (ECO) when compared to social factors (SOC)?
Q3. How important are environmental factors (ENV) when compared to social factors (SOC)?

With respect to: overall objective — Preference of one factor over another

| Questions | Factors | Demonstrated Importance | Very Strong Importance | Strong Importance | Moderate Importance | Equal Importance | Moderate unimportant | Strong unimportant | Very Strong unimportant | Demonstrated unimportant | Factors |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ENV | | √ | | | | | | | | CO |
| 2 | ECO | | | | | | | | √ | | SOC |
| 3 | ENV | | | | | √ | | | | | SOC |

The overall results could be obtained by taking the geometric mean of individual evaluations. However, a single valuation could be obtained to represent the group's opinion with the help of Delphi Method (Delbecq et al., 1975; Okoli and Pawlowski, 2004). The Delphi methodology enables group problem-solving using an iterative process of problem definition and discussion, feedback, and revisions. The questionnaire responses were compiled and were then subjected to an evaluator group. The evaluator group consisted of seven experts, four from the academics and three from the industry. It was the same group, which helped in arriving at the relevant factors and developing the hierarchal structure as mentioned in sub-section 3.4.2; municipal solid waste management factors. After a thorough discussion, the experts finally arrived at the values as shown in Tables 3.4.5-8. So it can be said, that the matrix values are based on the opinion of forty experts.

**Table 3.4.5: Fuzzy evaluation matrix for the main MSWM factors**

| Factors | Environmental | Economic | Social |
|---|---|---|---|
| Environmental (ENV) | (1,1,1) | (2/3,1,2) | (3/2,2,5/2) |
| Economic (ECO) | (1/2,1,3/2) | (1,1,1) | (1/3,2/5,1/2) |
| Social (SOC) | (2/5,1/2,2/3) | (2,5/2,3) | (1,1,1) |

*C.R. = 0.00*

The values of fuzzy synthetic extents with respect to the main factors are calculated by applying formula (4) as below:

$S_{ENV} = (3.16, 4, 5.5) \otimes (0.076, 0.096, 0.119)$

$(0.240, 0.384, 0.654)$

$S_{ECO} = (1.83, 2.4, 3) \otimes (0.076, 0.096, 0.119)$

$(0.139, 0.230, 0.357)$

$S_{SOC} = (3.4, 4, 4.6) \otimes (0.076, 0.096, 0.119)$

$(0.258, 0.384, 0.547)$

The degrees of possibility are calculated using these values and formula (9) as below:

$V(S_{ENV} \geq S_{ECO}) = 1$

$V(S_{ENV} \geq S_{SOC}) = 1$

$V(S_{ECO} \geq S_{ENV}) = 0.431$

$V(S_{ECO} \geq S_{SOC}) = 0.391$

$V(S_{SOC} \geq S_{ENV}) = 1$

$V(S_{SOC} \geq S_{ECO}) = 1$

The weight vector of the main factors of the hierarchy can be calculated by using the formulas (10) and (11) as below:

$d'(\text{Env}) = V(S_{ENV} \geq S_{ECO}, S_{SOC}) = \min(1,1) = 1$

$d'(\text{Eco}) = V(S_{ECO} \geq S_{ENV}, S_{SOC}) = \min(0.431, 0.391) = 0.391$

$d'(\text{Soc}) = V(S_{SOC} \geq S_{ENV}, S_{ECO}) = \min(1,1) = 1$

$W' = (1, 0.391, 1)^T$

Hence, via normalization, the normalized vectors of the factors, environmental, economic and social, for the formulation of a scheme for MSWM are obtained as below:

$W_{Objective} = (0.42, 0.16, 0.42)^T$

**Table 3.4.6: Fuzzy evaluation matrix of the environmental sub- factors**

| Sub-factors | (A) | (R) | (C) | (L) |
|---|---|---|---|---|
| Amount of Waste (A) | (1,1,1) | (1/2, 1, 3/2) | (1, 3/2, 2) | (1, 3/2, 2) |
| % Recycle (R) | (2/3, 1, 2) | (1,1,1) | (1/2, 1, 3/2) | (1/2, 1, 3/2) |
| % Composted (C) | (1/2, 2/3, 1) | (2/3, 1, 2) | (1,1,1) | (3/2, 2, 5/2) |
| % Land filled (L) | (1/2, 2/3, 1) | (2/3, 1, 2) | (2/5, ½, 2/3) | (1,1,1) |

*C.R. = 0.005*

In a similar way, the importance weights of the sub-factors with respect to environmental sub-factors are calculated as below:

$W = (d\,(\mathrm{A}), d\,(\mathrm{R}), d\,(\mathrm{C}), d\,(\mathrm{L}))^{\mathrm{T}}$

$W_{\text{Environmental}}$ = (0.288, 0.249, 0.271, 0.192) $^{\mathrm{T}}$. It can be observed that amount of waste, % composted and % recycled play important role in the formulation of the scheme for MSWM.

The importance weights with respect to the economic sub-factors are calculated as follows:

**Table 3.4.7: Fuzzy evaluation matrix of the economic sub-factors**

| **Sub-factors** | **(W)** | **(D)** | **(O)** |
|---|---|---|---|
| Cost of waste collection (W) | (1,1,1) | (1/2, 1, 3/2) | (1, 3/2, 2) |
| Cost of disposal (D) | (2/3, 1, 2) | (1,1,1) | (1, 3/2, 2) |
| O& M cost (O) | (1/2, 2/3, 1) | (1/2, 2/3, 1) | (1,1,1) |

*C.R. =0.00*

$W = (d\,(\mathrm{W}), d\,(\mathrm{D}), d\,(\mathrm{O}))^{\mathrm{T}}$

$W_{\text{Economic}}$ = (0.384, 0.384, 0.232) $^{\mathrm{T}}$. From the weights calculated it can be concluded that the cost of waste collection and disposal are equally important and they are more important when compared to the O&M cost.

The importance weights with respect to the social sub-factors are calculated as follows:

**Table 3.4.8: Fuzzy evaluation matrix for social sub-factors**

| **Sub-factors** | **(P)** | **(R&C)** | **(E)** |
|---|---|---|---|
| Population Served (P) | (1,1,1) | (1/2, 1, 3/2) | (1/2, 1, 3/2) |
| % of population involved in recycling and composting (R&C) | (2/3, 1, 2) | (1,1,1) | (1,3/2,2) |
| Employment rates (E) | (2/3, 1, 2) | (1/2, 2/3,1) | (1,1,1) |

*C.R. = 0.00*

$W = (d\,(\mathrm{P}), d\,(\mathrm{R\&C}), d\,(\mathrm{E}))^{\mathrm{T}}$

$W_{\text{Social}}$ = (0.327, 0.373, 0.300) $^{\mathrm{T}}$ From the results obtained it can be concluded that the percentage of population involved in the recycling and composting has the most importance followed by the population served and lastly the employment rates.

Finally, considering the results obtained, composite priority weights for the factors of MSWM can be calculated as given in the Table 3.4.9. These composite weights enable to understand the relative importance among the various factors of the MSWM scheme.

**Table 3.4.9: Composite priority weights for MSWM factors**

| Main factors | Local weights | Sub-factors | Local weights | Global weights |
|---|---|---|---|---|
| Environmental | 0.42 | Amount of waste | 0.288 | 0.12096 |
| | | % recycled | 0.249 | 0.10458 |
| | | %composted | 0.271 | 0.11382 |
| | | %land filled | 0.192 | 0.08064 |
| Economic | 0.16 | Cost of waste collected | 0.384 | 0.06144 |
| | | Cost of disposal per tone | 0.384 | 0.06144 |
| | | O&M cost | 0.232 | 0.03712 |
| Social | 0.42 | Population served | 0.327 | 0.13734 |
| | | % of population involved in recycling and composting | 0.373 | 0.15666 |
| | | Employment rates | 0.3 | 0.1206 |

Based on these results, it may be concluded that the percentage of population involved in recycling and composting plays an important role in the formulation of scheme for MSWM followed by population served, amount of waste generated.

## 3.5 DISCUSSION ON PRIORITIZATION OF MSWM FACTORS

Decision-making in the area of waste management in India has always been problematic. Generally, the decision makers take decisions without the help of the decision-making tools resulting in waste problems and unsuccessful waste management programs. The study proposes an analytic framework for the identification of MSWM. The results show that both the environmental and social main factors are equally important in design of any MSWM plan, as the local weight generated is 0.42. However, the most important factors for developing a MSWM scheme are percentage of population involved in recycling and composting (0.373), population served (0.327) and amount of waste generated (0.288).

## 3.6 MODEL FOR INFECTIOUS WASTE MANAGEMENT CONTRACTORS

### *3.6.1 Infectious waste factors*

To comprehensively identify the factors required for the selection of contractors handling infectious waste a procedure similar to that for the MSWM was followed and people such as hospital managers, officials of municipalities and SWM experts were consulted. By this way finally 11 factors were retained in a grouped into three categories: equipment, qualifications and service capability. The important factors that emerged from the results of discussions are delineated in the Table 3.6.10.

**Table 3.6.10: Infectious solid waste factors**

| Factors | Description | Reference(s) |
|---|---|---|
| Container Storage | To provide (temporary, central) storage to the total amount waste according to its categorization. | Abdulla et al. (2008); Alagöz and Kocasoy (2008); Al-Wattar (2006); Pan and Chen (1997); Ruoyan et al. (2010) |
| Eliminate redundant use of machinery | Adoption of the best available equipments for the handling of the waste in order to reduce various hazards and phase out old and worn out machinery | Alagöz and Kocasoy (2008);Hsiao et al. (2004); Qiu (2001) |
| MIS | Managing Information System | Askarian et al. (2004); Yang et al. (2002) |
| Waste Discarded | Efficiently deal with the waste discarded | Abdulla et al. (2008); Alagöz and Kocasoy (2008); Ruoyan et al. (2010); Yang et al. (2002) |
| Environmental Standards | Conform to environmental standards | Ruoyan et al. (2010); Yang et al. (2002) |
| GPS | Provide GPS to standardize the transportation system | Gu and Pan (1999), Chen (2000) |
| Invoice Documentation | Provide correct invoice documentation and maintain log of the waste generated and handled | Chen (2000); Gu and Pan (1999); Ruoyan et al. (2010) |
| Additional Services | Provide additional services promptly in view of contingency | Siru et al. (2006) Yang et al. (2002) |
| Appeal Process | Swift demand process in case of emergency | Siru et al. (2006) Chen (2000) |
| Program Alternatives | Clarify program alternatives | Fu (1998); Ruoyan et al. (2010); Siru, Pillay and Sinha. (2006) |
| Specialized Skills | Explain specialized skills such as staff training, occupational safety& education and spill control | Abdulla et al. (2008); Alagöz and Kocasoy (2008); Chung and Carlos (2003); Ruoyan et al. (2010); Yang et al. (2002) |

The hierarchy developed for the factors for the selection of the infectious waste contractors is shown in the Figure 3.3.

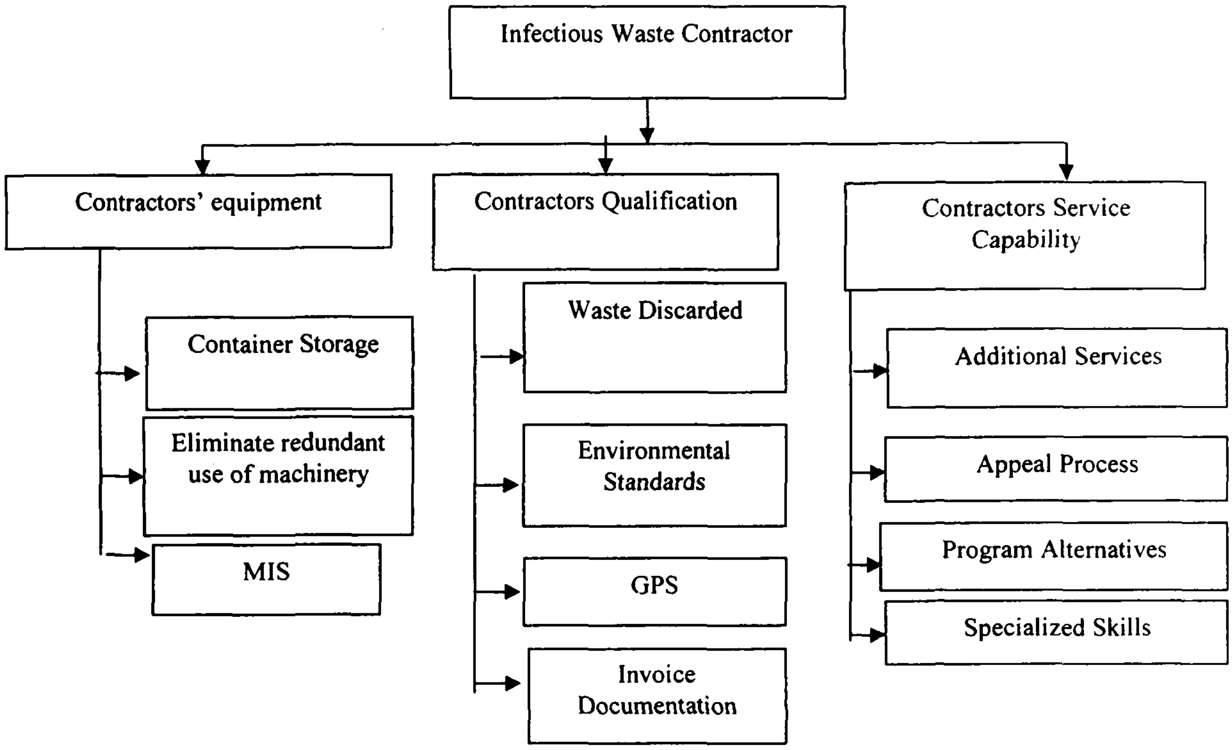


**Figure 3.3: Hierarchy model for the determination of infectious waste factors**

A procedure similar to the analysis of the MSW questionnaire was adopted for the infectious waste. Table 3.6.11 depicts the sample questionnaire developed for the prioritizing infectious waste contractors. In all thirty questionnaires were mailed to the different health-care institutes. In addition, ten experts were contacted personally by the authors. Five were from the academia and the rest five were from the health-care establishments, which were outsourcing the disposal of the infectious waste. From the mailed questionnaires 18 were returned; indicating a 60 percent of response, which is an acceptable response. The questionnaire responses were compiled and were then subjected to an evaluator group. The evaluator group consisted of nine experts, two from the academics, five from the health-care institutes and two from the municipality. After a thorough discussion, the experts finally arrived at the values as shown in Tables 3.6.12-16.

**Table 3.6.11: Sample questions from the HWM questionnaire**

With respect to the overall objective, evaluate the following infectious waste factors

Q1. How important are contractor's equipment (EQP) factors when compared to contractors qualification (QUL) factors?

Q2. How important are contractor's qualification (QUL) factors when compared to contractors service capability (SC) factors?

Q3. How important are contractor's equipment (EQP) factors when compared to contractors service capability (SC) factors?

With respect to: overall objective — Preference of one factor over another

| Questions | Factors | Demonstrated Importance | Very Strong Importance | Strong Importance | Moderate Importance | Equal Importance | Moderate unimportan | Strong unimportan | Very Strong unimportan | Demonstrated unimportan | Factors |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | EQP | | | | √ | | | | | | QUL |
| 2 | QUL | | | | | | √ | | | | SC |
| 3 | SC | | √ | | | | | | | | EQP |

**Table 3.6.12: Fuzzy evaluation matrix for the main factors for selection of contractors**

| Main factors | Equipment | Qualification | Service capability |
|---|---|---|---|
| Contractors equipment (EQP) | (1,1,1) | (1/2,1,3/2) | (2/5,1/2,2/3) |
| Contractors qualification (QUL) | (1,3/2,2) | (1,1,1) | (1/2,1,3/2) |
| Contractors service capability (SC) | (3/2,2,5/2) | (2/3,1,2) | (1,1,1) |

*C.R. = 0.005*

The values of fuzzy synthetic extents with respect to the main factors are calculated by applying formula (4) as follows:

$S_{EQP} = (1.9, 2.5, 3.16) \otimes (0.076, 0.1, 0.132)$

$(0.144, 0.25, 0.417)$

$S_{QUL} = (2.5, 3.5, 4.5) \otimes (0.076, 0.\ 1, 0.132)$

$(0.19, 0.35, 0.594)$

$S_{SC} = (3.16, 4, 5.5) \otimes (0.076, 0.1, 0.132)$

$(0.24, 0.4, 0.726)$

The degrees of possibility are calculated using these values and formula (9) as below:

$V(S_{EQP} \geq S_{QUL}) = 0.694$

$V(S_{EQP} \geq S_{SC}) = 0.541$

$V(S_{QUL} \geq S_{EQP}) = 1$

$V(S_{QUL} \geq S_{SC}) = 0.876$

$V(S_{SC} \geq S_{EQP}) = 1$

$V(S_{SC} \geq S_{QUL}) = 1$

The weight vector of the main factors of the hierarchy can be calculated by using the formulas (10) and (11) as below:

$d'(EQP) = V(S_{EQP} \geq S_{QUL}, S_{SC}) = \min(0.694, 0.541) = 0.541$

$d'(QUL) = V(S_{QUL} \geq S_{EQP}, S_{SC}) = \min(1, 0.876) = 0.876$

$d'(SC) = V(S_{SC} \geq S_{EQP}, S_{QUL}) = \min(1,1) = 1$

$W' = (0.541, 0.876, 1)^T$

Hence, via normalization, the normalized vectors of the factors, equipment, qualification and service capability, for the selection of infectious waste handling contractors are obtained as below:

$W_{objective} = (0.22, 0.36, 0.42)^T$

**Table 3.6.13: Fuzzy evaluation matrix of the equipment sub- factors**

| **Sub-factors** | **Container storage** | **Redundant machinery** | **MIS** |
|---|---|---|---|
| Container Storage (C) | (1,1,1) | (1,3/2,2) | (1, 3/2, 2) |
| Redundant Machinery (R) | (1/2, 2/3, 1) | (1,1,1) | (1/2, 1, 3/2) |
| MIS (M) | (1/2,2/3,1) | (2/3, 1, 2) | (1,1,1) |

*C.R. =0.00*

In a similar way, the importance weights of the sub-factors with respect to equipment sub-factors are calculated as below:

$W = (d(C), d(R), d(M))^T$

$W_{Equipment} = (0.43, 0.27, 0.3)^T$. It can be observed that container storage, and managing information system play important role in the selection of infectious waste handling contractors.

The importance weights with respect to the qualifications sub-factors are calculated as in Table 3.6.14.

**Table 3.6.14: Fuzzy evaluation matrix of the qualification sub-factors**

| **Sub-factors** | **Waste discarded** | **Environmental standards** | **GPS** | **Invoice documentation** |
|---|---|---|---|---|
| Waste discarded (W) | (1,1,1) | (1/2, 2/3,1) | (1/2,1, 3/2) | (3/2,2,5/2) |
| Environmental standards (E) | (1, 3/2,2) | (1,1,1) | (1, 3/2, 2) | (3/2,2,5/2) |
| GPS(G) | ( 2/3, 1,2) | (1/2, 2/3, 1) | (1,1,1) | (1/2,1, 3/2) |
| Invoice documentation (I) | (2/5,1/2,2/3) | (2/5,1/2,2/3) | ( 2/3, 1,2) | (1,1,1) |

*C.R. =0.07*

$W = (d\,(\mathrm{W}), d\,(\mathrm{E}), d\,(\mathrm{G}), d\,(\mathrm{I}))^{\mathrm{T}}$

$W_{Qualification}$= (0.3, 0.4, 01.3, 0.17) $^{\mathrm{T}}$. From the weights calculated it can be concluded that the conforming to environmental standards, efficiently dealing with the waste discarded, and correct invoice documentation are more important then the installing GPS in the transport carrier of the waste.

The importance weights with respect to the service capability sub-factors are calculated as follows:

**Table 3.6.15: Fuzzy evaluation matrix for service capability sub-factors**

| **Sub-factors** | **Additional service** | **Appeal process** | **Program alternatives** | **Specialized skills** |
|---|---|---|---|---|
| Additional services (S) | (1,1,1) | (2/5,1/2,2/3) | (1/2, 2/3,1) | (1/2, 1, 3/2) |
| Appeal process (P) | (3/2,2,5/2) | (1,1,1) | (1,3/2,2) | (3/2,2,5/2) |
| Program alternatives (A) | (1,3/2,2) | (1/2, 2/3,1) | (1,1,1) | (1/2, 1, 3/2) |
| Specialized skills (SS) | (2/3, 1, 2) | (2/5,1/2,2/3) | (2/3, 1, 2) | (1,1,1) |

*C.R. = 0.05*

$W = (d\,(\mathrm{S}), d\,(\mathrm{P}), d\,(\mathrm{A}), d\,(\mathrm{SS}))^{\mathrm{T}}$

$W_{\text{Service Capability}}$ = (0.15, 0.36, 0.26, 0.23) $^{\mathrm{T}}$ From the results obtained it can be concluded that the speeding up appeal process and clarifying program alternatives have more importance than the clarifying specialized skills and providing additional services. Finally, considering the results obtained, composite priority weights for the factors for selection of infectious waste contractors can be calculated as given in the Table 3.6.16. Based on these results, it may be concluded that the speeding up appeal process, conforming to environmental standards, and efficiently dealing with the waste discarded play an important role in the selection of the infectious waste handling contractors.

**Table 3.6.16: Composite priority weights of factors for selection of infectious waste contractors**

| Main Factors | Local weights | Sub-factors | Local weights | Global Weights |
|---|---|---|---|---|
| Equipment | 0.22 | Container Storage | 0.43 | 0.0946 |
| | | Redundant Machinery | 0.27 | 0.0594 |
| | | MIS | 0.30 | 0.0660 |
| Qualification | 0.36 | Discarded Waste | 0.30 | 0.108 |
| | | Environmental Standards | 0.40 | 0.144 |
| | | GPS | 0.13 | 0.0468 |
| | | Invoice Documentation | 0.17 | 0.0612 |
| Service Capability | 0.42 | Additional Services | 0.15 | 0.0630 |
| | | Appeal Process | 0.36 | 0.1512 |
| | | Program Alternatives | 0.26 | 0.1092 |
| | | Specialized Skills | 0.23 | 0.0966 |

## 3.7 DISCUSSION ON MODEL FOR PRIORITAZATION OF FACTORS FOR INFECTIOUS WASTE CONTRACTORS

Selecting an appropriate infectious medical waste disposal contractor is often a subjective task. Especially in the medical sector, hospital managers lack precise and objective decision-making procedures and evaluation criteria. Therefore, integrating quantitative methods into the evaluation procedure enables decision makers to identify the most appropriate infectious medical waste disposal contractor objectively and efficiently.

Analysis results indicate that the medical sector selects the most appropriate infectious medical waste disposal firm based on the following rank: contractor's service capability (0.42), contractor's qualifications (0.36), and contractor's equipment (0.22) respectively. According to the regulations in India, the hospital also has to take the legal responsibilities if the contractor improperly handles the medical waste. Therefore, the hospitals value the contractor's service capability, qualifications and much more then its equipment factors.

## 3.8 CONCLUSIONS

The hierarchy, for both the model on MSWM and infectious waste factors, has been developed by the help of existing literature and consulting experts, academia, officials of the municipalities and hospital mangers. In general, the evaluation problems adhere to uncertain and imprecise data, and fuzzy set theory is an important tool to model such situations (Büyüközkan, 2009). After identifying the factors, fuzzy AHP methodology has been used to prioritize these factors by determining their relative weights. Though the process of garnering response was strenuous, but the actual application of fuzzy AHP methodology applied in this chapter is less time taking and cumbersome as compared to other existing decision-making systems (Bozbura et al., 2007; Büyüközkan, 2004; Chan and Kumar, 2007; Kulak and Kahraman, 2005; Kwong and Bai, 2003), since it doesn't include lengthy calculations. Percentage of people involved in recycling and composting, percentage of population served and amount of waste generated are important factors for the MSWM prioritization, while speeding up appeal process, conforming to environmental standards, and efficiently dealing with the infectious waste discarded are the major factors in prioritizing the infectious waste contractors. These results can be useful to researchers, to the local authorities, hospital management staff and those involved in the SWM. The results obtained from the model underscore the importance of segregating waste at the point of origin. Hence, the local civic bodies like municipalities should encourage people, on a large scale, to segregate the waste generated into recyclables and compostable matter, as being done in some metropolitan cities of the country such as Delhi. This will not only enable the municipalities to work efficiently, but will also enable the civic agency to include the population that is currently not being served. Another, important implication of encouraging people to segregate would reduce the burden on the environment and on government exchequer, as less area of land would be needed to dispose off the waste in the landfills. Conforming to the environmental standards and innocuous disposal of waste are major factors for the prioritization of both types of factors as more and more people are becoming aware of the environmental degradation due to the solid waste.

Fuzzy-AHP methodology developed for the MSWM and infectious waste factors would help top management to focus their efforts towards the roots of the problems. This would certainly help health-care organizations to be well prepared and combat hazards and nuisance created from generation of bio-medical solid waste more effectively. Though from these two models management would be able to identify variables and are the key for effective SWM, still it won't be able to decide which strategy to follow or select the best available option in actual scenario. Thus, to facilitate the management to select the best approach or the option to design and formulate a SWM plan an analytic network process based model is developed as presented in the next chapter.

## 3.9 LIMITATIONS AND SCOPE FOR FUTURE RESEARCH

The proposed framework for the MSWM was developed with data from the northern part of India. In future, this can be replicated for other regions as well as for different countries. The proposed methodology may serve as a guideline to many solid waste management problems. Such models can be developed for various environment related problems. Both types of solid wastes handling is a complex system of various factors. There may be interaction and interdependencies among various factors. However, in this study fuzzy AHP methodology has been applied with an assumption of independency. It is clear that additional model refinement is required to capture and understand all the interdependencies etc among the factors. The analytic network process (ANP) ( Saaty, 1996), the general form of AHP, is capable of handling interdependence among the elements by obtaining composite weights. This method has been recently developed to be used in fuzzy environment (Büyüközkan et al, 2004). Further research may include the application of this method to the factors for selection of appropriate municipal solid waste techniques and selection of the best available infectious waste handling contractor.

Also, such models are not universal as the situation may involve certain biases on the part of decision makers and human errors in understanding the basic difficulties, which may lead to skewed results and solutions. The method presented in this paper warrants further research in subjecting the model to sensitivity analysis. However, the model presented here may serve as a reference point in evaluating the problems related to environmental issues. Further evaluation of the model and modifications according to specific needs by addition or deletion of certain elements in the model may prove beneficial in this field of study and would help in developing a system that would enable the decision-makers to solve SWM problems in a more transparent and systematic manner.

# CHAPTER 4

# ANALYTIC NETWORK PROCESS MODEL FOR SELECTION OF ALTERNATIVES

## 4.1 INTRODUCTION

Solid waste generation is concurrent with every activity and progress. The posit of completely eliminating waste is highly unrealistic and the best approach is to handle the solid waste in such a manner that it is not only innocuous in terms of the environment, but is also supported by the denizens of a place who are directly impacted by the solid waste management (SWM) program in an area. Therefore, waste management is one of the priority issues concerning protection of the environment and conservation of natural resources. In fact, managers and planners are paying increasing attention to formulating and following a sustainable approach to waste management by integrating strategies that will produce the best practical option. The task of sustainable, integrated solid waste management is difficult as it necessitates taking properly into account factors as diverse as economic, technical, and normative aspects, with particular attention to environmental issues.

---

*A part of this chapter has been published as:*

*'An analytic network process model for municipal solid waste disposal options', (2008),* ***Waste Management****, Vol. 28, pp. 1500–1508.*

*A part of this chapter has been accepted for publication as:*

*An analytic process model for selection of infectious waste management contractors',* ***International Journal of Mathematics in Operational Research****, (Inderscience Publication)*

In India municipal solid waste management (MSWM) is done by the civic agency or the municipalities and there are often conflicts between people and local body officials with regard to the site of the solid waste facility and the scheme that is to be adopted in disposal of the solid waste. Solid waste disposal and management is not only a social problem but is an amalgamation of political, socio-cultural, technical, fiscal and environmental factors. Often while formulating and adopting a strategy of disposal of the solid waste, the municipal authorities over-look one or more of the important factors that make the solid waste disposal a poorly performed service, resulting in environmental degradation, lack of sanitation and a plethora of health problems.

This kind of decision-making environment involves an ill-defined problem in which behavioral decision research shows that humans are typically quite ineffective at solving, problems involving SWM unaided ( Promentilla et al., 2006). In this context, decision support tools (DST) such as multi-criteria decision-making (MCDM) have been recognized to play a vital and challenging role in SWM (Charnpratheep et al., 1997; Chen and Chang, 2000; Hung et al., 2006). Moreover, the DST can facilitate communication among decision-makers and stake-holders in reaching a justifiable decision through a systematic, transparent and documented process. With these considerations, the chapter proposes to use analytic network process (ANP), a MCDM tool, to evaluate the different alternatives of waste disposal in a large city in India.

With the proliferation of blood born diseases, more attention is being paid on the issue of infectious medical waste and its disposal. Health-care institutions must be aware of the potential risk in handling infectious waste, and must adhere to the highest standards of disposal and transport. Education of the staff, patients and community about the management of the infectious waste is crucial in today's health-care arena. The increasing awareness in general population regarding hazards of hospital waste, public interest litigations were filed against erring officials and health-care institutes leading to some landmark decisions to streamline hospital waste management. The Ministry of Environment & Forest (MoEF), Government of India issued a notification for Bio-medical Waste (Management & Handling) Rules 1998 accepting that it is a primary responsibility of the government to implement the recommendations and directions of the Supreme Court of India and Biomedical Waste

(Management & Handling) Rules 1998 in public interest, so that biomedical waste does not cause any harm to men, animal and environment.

Approximately 7000 metric tons of solid waste is generated in Delhi, out of which 70 tons are bio-medical or infectious waste. The state owned hospitals and major private hospitals have their own arrangement for treatment of bio-medical waste disposal, but the small and medium health-care institutes face difficulties in adhering to the rules promulgated in 1998. Keeping in view the difficulties faced by smaller nursing homes/clinics/blood banks/diagnostic laboratories etc., the Government has taken initiatives to establish centralized waste treatment facilities through out India. The small and medium sized health-care establishments outsource the collection, handling and transportation of the bio-medical or infectious to an agency or a contractor in order to abide by the rules and regulations. If infectious waste is inadequately managed, the microorganisms breeding inside can be transmitted by direct contact, in the air or by a variety of vectors, and can pose a serious threat to human health and to the environment. The inefficient handling of this solid waste is more likely to cause problems such as blood borne pathogens to the groups at highest risk, namely: health-care staff, scavengers, and municipal workers (Soliman and Ahmed, 2007). As discussed earlier in section 2.4.2 solid infectious waste in any urban locality is approximately 1% of total municipal solid waste (MSW), but if handled improperly, the infectious waste has the potential of spreading the infection in the surroundings by microbial proliferation. As the incidence of several diseases (such as HIV and hepatitis) is on the rise, their incidence in the health-care environment is likely to be higher, resulting in enhanced risks and exposure to the health-care providers and waste handlers (Becker, Cone and Gerberding, 1989). However, the institutions do not comply with the rules and the conditions within them are pathetic. Therefore, there is urgent need to improve upon the medical waste management practices.

Some of the major health-care facilities (HCFs) in India are treating the infectious waste by on-site incinerators or steam sterilization facilities at some general hospitals, where incinerators or steam sterilization is available, small and medium HCFs may not be in a position to install required equipment on their premises. It may, therefore, be appropriate for small HCFs to outsource waste management, handling and disposal. Ruoyan et al. (2010)

observed regarding the small or the primary health-centers in handling infectious waste that off-site treatment for the small and medium HCFs is important not only because of economic considerations, but also for the environmental implications. It is noted that off-site disposal allows the local environmental authority to monitor management system and handling procedures effectively. Thus, making the selection of appropriate infectious waste handling contractors an onerous task for the medium and small and medium HCFs due to the number of safeguards as discussed previously in the sub-section section 2.4.2. For effective infectious waste management the various factors that are taken in consideration, while appointing a contractor should be identified correctly and should be given due importance for the plan to be a success. Hence, it is essential to identify infectious waste management factors for setting satisfactory system standards. Therefore, selection of contractor can be viewed as a complex multi-criteria decision-making (MCDM) problem, as it is a combination of various factors such as their capability, qualification etc.

In this chapter, an ANP-based model has been developed for selecting a municipal solid waste disposal option and selecting the most appropriate infectious waste managing contractor. The chapter is organized as follows: Section 4.2 presents a brief literature review. It includes reviews of the published papers in which any kind of MCDM has been done to conclude a SWM related problem. Next, section 4.3 of the chapter discusses the methodology for developing the ANP model. Section 4.4 defines the objectives of the chapter. The selection of the available alternatives for any kind of waste management is a comprehensive method. For the purpose of selecting the best alternative of MSWM disposal major actors, five major criteria or the determinants and several sub-criteria; enablers have been identified (Fig 4.1). Section 4.5 gives the model developed for the MSWM alternative selection. The discussion for the results obtained is given in section 4.6. The factors for the selection of the infectious waste contractor are the same as discussed in the section 3.6.1. The ANP model developed, as depicted in figure 4.2, shows the various interdependencies and interaction of the different variables identified in the previous chapter. The ANP model for the selection of the infectious waste contractor is developed in section 4.7. The section 4.8 discusses the solution for the model followed by section 4.9, where the analysis to the results has been used to arrive upon conclusions.

## 4.2 LITERATURE REVIEW

As discussed in section 2.2 Bana e Costa et al. (1997) provides a brief history of the origins of multi-criteria evaluation methods. An underlying characteristic of all MCDM applications is that several individual and often conflicting criteria are taken into account to make more robust decision-making, which is completely multi-dimensional. Unlike other modeling tools the objective of the MCDM tools such as AHP or ANP is not optimizing a single dimensional objective function, (such as cost benefit analysis) rather they strike a balance among different conflicting criteria and priorities to arrive upon a viable solution to the problem. Thus, in a way MCDM applications lead to understanding the environmental problems in a holistic perspective. In addition, the multi-criteria approach assists decision-makers not only to learn about the problem, but to explore and approach the problem with alternative courses of action from several points of view. The normal approach is to identify several alternatives, (such as different waste disposal options) which are then evaluated according to the pertinent criteria for the model or the circumstances for which the model being developed. A rank of the different alternatives emerges as a result of the MCDM techniques used.

In recent years, decision models based on life cycle analysis (LCA) and MCDM have become popular. Earlier, models were developed for optimization, where models assumed that the different objectives of the proposal can be expressed in a common denominator or scale of measurement, whereby the loss in one objective can be directly evaluated against a gain in another (Morrissey and Browne, 2004a). But in contemporary models like those based on MCDM, the objective is that by reaching a compromise between different priorities a solution is worked out. The viable solution is the one that performs well among all other alternatives when compared with the same set of priorities. The inconsistencies between the actual scenario and the ideal conditions are delineated as the preference weights of the various criteria. Table 4.2.1 depicts some of the popular software tools available for the MCDM.

**Table 4.2.1: Some of the software tools for MCDM***

| **Software** | **Application** |
|---|---|
| EXPERT CHOICE | For AHP. (Forman, 1998) |
| ELECTRE TRI Assistant | for ELECTRE TRI (Mousseau et al., 2000) |
| HIPRE 3+ | HIPRE 3+ is a decision support software product integrating AHP and SMART—The Simple Multiattribute Rating Technique. Both methods can run independently or be combined in one model. (http://www.sal.hut.fi/Downloadables/) |
| HiView | Hiview is a multi-criteria decision analysis (MCDA) tool that supports decisions regarding mutually exclusive options, using a technique called MACBETH (http://www.catalyze.co.uk/hiview/hiview.html) |
| LOGICAL DECISIONS | Used with multi-attribute utility theory. The software provides five different methods for assessing weights, ranging from the "Smarter" method to AHP (http://www.logicaldecisions.com/prod01.htm) |
| PREFCALC, MINORA, VIG, LBS, CAMOS, M.H.DAS, ADELAIS, MARKEX, UTA+, FINEVA, FINCLAS, MUSTARD | Identified by Siskos (1999) and Jacquet-Lagreze and Siskos (2001) as examples of Third and Fourth generation Multicriteria Decision Support Systems (MCDSSs) and most of which are UTA based. |
| PREFDIS system | PREFDIS system uses the UTADIS method to develop additive utility functions for sorting problems involving two or more groups. (Zopounidis and Doumpos, 2002) |
| PROMCALC | For the PROMETHEE method (de Keyser and Peeters, 1996) |
| RANGU system | Developed by Stam and Ungar, this develops discriminant functions for two-group classification. (Zopounidis and Doumpos, 2002) |
| ROSE system | Developed by Predki and others is based on the rough set method (Zopounidis and Doumpos, 2002) |

**Adapted from Morrissey and Brown (2004a)*

Health-care is a basic need for current and future generations (UNDP, 2005), and is therefore, one of the objectives of sustainable development systems. In developing countries, with large population, where poor health is one of the reasons for high mortality rate; provision of adequate health-care burdens the already overloaded and under-funded local civic authorities involved in solid waste management. WHO (2005) reports that 22 developing nations have inappropriate health-care waste management. About 18% to 64% of the health-care facilities use in adequate waste disposal methods.

Brent et al. (2007) apply the MCDM techniques analytical hierarchy process (AHP) to establish and optimize health-care waste management (HCWM) systems in developing countries. They evaluate the AHP with a life cycle management (LCM) approach, and addressing a main objective of HCWM systems, i.e. to minimize infection of patients and workers within the system. Yang et al. (2009) mention that in China the HCWM is mainly promoted by the under-financed government bodies. The existing HCWM is not holistic, since there is lack of implementation of an effective system of regulations, standards, and a suitable supervision and control scheme. Moreover, it suffers effective implementation due to the functions and interactions of several agencies and institutions. There is the need for a technical regulatory system that covers waste collection, classification, storage, transportation, treatment, and disposal not only environmentally innocuous, but with a lifecycle perspective. The authors further state that the personnel engaged in the HCWM have insufficient and public environmental awareness, which needs to be substantially increased. Only a few of them have had specific professional training in order to competently carry out the obligations of their HCWM posts. This scenario such as poor waste separation, lack of equipment, unsanitary storage locations, deficient protective measures, and unsafe on-site disposal replicates in the other developing countries such as India, Indonesia, Iran, Tanzania and Turkey (Alagöz and Kocasoy, 2008; Askarian, Vakili and Kabir, 2004; Chaerul, Tanaka and Shekdar, 2008; Mato and Kassenga, 1997). The hospital management often overlooks various issues such as safety and public health, as well as environmental conservation, necessitating the professional help of infectious waste management contractors.

On the other hand, the developed world is faced with growing amount of health-care waste originating from the residential areas. According to Blenkharn (2008), there are increasing numbers of patients receiving complex home-based health-care, contributing to the substantial volumes of infectious waste. Arrangements for the collection and safe disposal of these potentially hazardous wastes, generally managed by local authorities, may be inadequate and, in part, unsafe. He further states that many local authorities are unable to provide safe and effective infectious waste collection services resulting in potentially hazardous wastes deliberately placed in the street in locations accessible to passers by. There are not only safety and health implications, but also breach of the environmental legislation; thus aggravating environmental risk. The research published entails that it is all the more important that a competent agency, which can handle infectious waste is given the task of managing the health-care waste, so as to minimize health and environmental risks and provide safety to public at large.

The promulgation of various political, social, and economic pressures regarding environmental issues have made the organizations to take them into account, while devising their strategy, operations and formulating their goals (Sarkis et al., 2010). They need to manage the many perspectives and conflicting interests, which requires them to develop specific capabilities to manage these pressures (Rueda-Manzanares et al., 2008). However, in India, the need to be profitable and competitive in the health-sector makes the top management think little for their environmental responsibilities. There is more focus on other goals by top management in the hospitals, which not only leads to lack of allocation of funds for proper acquisition and adoption of modern treatment methods for hospital waste, but to mismanagement of the infectious waste as well. (Faisal et al. Accepted). It is interesting that most of the hospitals in Delhi, the capital of India, are violating BMW 1998 rules and mismanaging infectious waste by transporting waste in open hand-pulled carts, dumping it in open or worse mixing it with the MSW. According to a survey conducted, 93 per cent of the surveyed hospitals have been defaulters (Patil and Shekdar, 2001; Singh 2001). Therefore, there is an urgent need to address the problem of infectious waste management, which can be effectively solved if professional help of the infectious waste handlers is taken. However, from an organizational perspective appointing a capable infectious waste contractor can be a formidable project, if appropriate techniques are unavailable and correct issues are not short-listed.

There is increasing popularity of the MCDM technique ANP in various applications like evaluation of environmentally conscious business practices (Sarkis, 1998), logistic strategy analysis (Meade and Sarkis, 1998), supply chain and reverse logistics (Meade and Sarkis, 1999; Jharkaria and Shankar, 2005; Aggarwal et al., 2005) energy policy (Hamalainen and Seppalainen, 1986; Erdogmus et al., 2006; Ulutas, 2005), construction planning, and project selection (Chen et al., 2005; Cheng and Li, 2005). Though a beginning has been made (Promentilla et al., 2006), ANP as a decision making technique has yet to gain recognition in waste management and its related problems.

## 4.3 RESEARCH OBJECTIVES

In the literature review no study was found that evaluated waste disposal options in India using MCDM, which includes criteria such as environmental, social, financial and technical to arrive upon an option to dispose solid waste. Also, no study evaluated the different infectious waste contractors using ANP. Therefore, the aim of this work is to present a structure of MCDM using ANP to help decision makers of a municipality in the development of integrated disposal programs

A. To analyze criteria and determinants of municipal solid waste management

B. To develop a model to select the best alternative for effective solid waste disposal, and

C. To test the analytical model for actual data from the field.

The objectives of the second model for the selection of the best contractor for the management of the infectious waste are similar to the above objectives and include:

A. To analyze criteria and determinants of infectious waste contractors

B. To develop a model to select the best contractor available for management of infectious waste, and

C. To test the model for the actual field data.

## 4.4 METHODOLOGY

This chapter proposes an analytic network process (ANP) model to achieve the objectives listed above. ANP is the generalization of Saaty's analytical hierarchy process (AHP), which is one of the most widely employed decision support tools. AHP is limited to relatively static and unidirectional interactions with little feedback among decision components and alternatives (Sarkis, 1998). On the other hand, ANP and its super matrix technique can be considered as an extension of AHP to handle a more complex decision structure (Saaty, 1996; 2001), as ANP framework has the flexibility to consider more complex interrelationships (outer dependence) among different elements. It incorporates both qualitative and quantitative approaches to a decision problem (Cheng and Li, 2005). It is also capable of capturing the tangible and intangible aspects of relative criteria that have some bearing on the decision-making process (Saaty, 1996), but AHP cannot deal with interconnections (inner dependence) between decision factors in the same level. This is because an AHP model is structured in a hierarchy in which no horizontal links are allowed. *In fact, this weakness can be overcome by using the advance multi-criteria making technique* ANP. Thus, ANP is a combination of three parts: the first part is the control hierarchy of the network of the criteria, sub-criteria or the second part is a network of influences among the elements and clusters, and third is the feedback between the various clusters and elements within a cluster.

Therefore, ANP is a more powerful technique in modeling complex decision environments than AHP because it can be used to model very sophisticated decisions involving a variety of interactions and dependencies (Meade and Sarkis, 1999; Saaty, 1999) that exist in the real world problems like selecting a waste disposal method or selecting a waste contractor, which are a gridlock of various issues.

## 4.5 SELECTION OF DISPOSAL OPTIONS FOR MSW

### *4.5.1 Selection Criteria*

In order to develop an ANP model, a thorough search of the literature published was done and informal discussions with the officials of the municipality, academics and the experts working in the field of waste management were carried out. The discussions helped in making a hiernet consisting of different criteria, as described in Table 4.5.2, classified into various categories to evaluate different alternatives of solid waste disposal.

**Table 4.5.2: Description of selection criteria for MSW disposal option**

| Criteria | Description |
|---|---|
| Civic Agency (CA) | The body that is entrusted to provide the sanitation and conservancy in the city |
| People (POP) | People who are directly impacted by the MSWM |
| Local Government (LG) | The elected representatives of the people who constitute the local body assembly etc. and influence all the strategies and the decisions of the civic agency |
| Operations and Management (O&M) | Day- to- day operations and management of the solid waste disposal at the facility is an important factor in the selection of the best option |
| Social Acceptance (SA) | No alternative is viable until it has acceptance from people from all the quarters, community, political and environmentally conscious groups |
| Financial (FIN) | For selecting an alternative capital and operational costs play an important role |
| Technical (TECH) | Required technology and expertise should be available for the selecting a particular alternative |
| Environmental Feasibility (EF) | The option selected should dispose the waste innocuously and should be in concurrence with sound environmental practices and legalities |
| Personnel (PER) | Adequate number of personnel who are appropriately trained to carry out operations and management at the disposal facility are must |
| Equipments (EQP) | To carry out the smooth operation of disposing the waste it is essential that the personnel who are involved in carrying out the operations be equipped with appropriate tools |
| Community Support (CS) | In order to adopt better SWM practices it is incumbent that the concerns and the concepts of the people at large should be taken into account |
| Political Support (PS) | Political will and support is essential in order to formulate and adopt sound environmental and people-friendly SWM practices |
| Environmental Groups (EG) | To select the viable disposal option it is essential that the environmentally conscious groups should be consulted and the scheme of the SWM should be such that it is in accordance with the concerns of such groups |
| Capital Cost (CC) | The cost that will be incurred to construct and the post- closure of the solid waste disposal facility |
| Operational Cost (OC) | *The cost incurred on the day-to-day operations of the disposal of waste* |

| Criteria | Description |
|---|---|
| Budget Control (BC) | One of the financial constraint that influences the selection of the most appropriate option |
| Know-how (KH) | The technological expertise that is required to set-up a particular disposal facility |
| Technical Implications (TI) | The technology adopted for the disposal scheme should be such that it is suitable for the waste characteristics and can be replicated at other places with some modifications and should be designed so that it has the capacity to serve sudden surge or dawdle |
| Rules &Regulations (R&R) | To select an alternative it is essential that the local and the national laws and regulations be conformed and the environmental bodies like the pollution boards etc. should give environmental clearance for the implementation of the project |
| Geographical Location (GL) | For an option to be viable the geographical location should be such that it conforms to all the environ-legal criteria and has no inherent construction problems |
| Health & Safety (H&S) | Occupational health and safety (OHS) is one of the most important criteria for protecting workers health on site (Lingard 2002, Khan 2006). Alternative that is to be selected must be able to conform to this measure |

### *4.5.2 Analytic Network Model*

Prior to applying the ANP model to the problem of selecting the best disposal option, informal discussions were carried out with the people who formed the stake-holders or the actors in the model. These are the officials in the municipality, councilors, and members of the local assembly, people working with the non-governmental organizations (NGOs) in the field of environment, experts and academics working in the research of solid waste management, members of the resident welfare associations (RWAs), and local market associations. Private players like the waste management companies have recently started operating in selected areas of cites like Delhi and Mumbai. They did not form the part of the group of stake holders as their presence is very limited. Including them may have skewed the results. The informal discussions carried out at this stage helped to develop better understanding of the MSWM practices and internal hospital waste management. Further, the information garnered through this method also facilitated the process of pairwise comparison of the different criteria of the model.

### *4.5.3 Step I: ANP Model Construction*

*MSWM model*

The ANP model, depicted in Figure 4.1, in this chapter consists of five levels. The first level is the decision problem that is to prioritize the waste disposal method. The second level is that of the actors that influence the prioritizing of the alternatives. This level consists of three elements: civic agency, people and the local government. These actors play an important role in viewing the problem differently and may have different or conflicting views regarding the various criteria, which are influential in the selection of the best alternative. ANP is a technique that helps to integrate their expectations to form the composite category weights after taking into account their various interests (Cheng and Li, 2005). The third level is the criteria or the determinants upon which the prioritization of the waste disposal method is broadly based. This level is divided into five major components: operations and management, social acceptability, financial, technological, and environmental feasibility. The next level consists of the enablers or the sub-criteria that support the determinants. The last or the fifth level consists of the three different alternatives that have to be evaluated through the ANP model based upon the several criteria. These alternatives are:

A. Waste disposal through land filling and composting

B. Waste disposal through land filling, composting and incineration

C. Waste disposal through land filling only

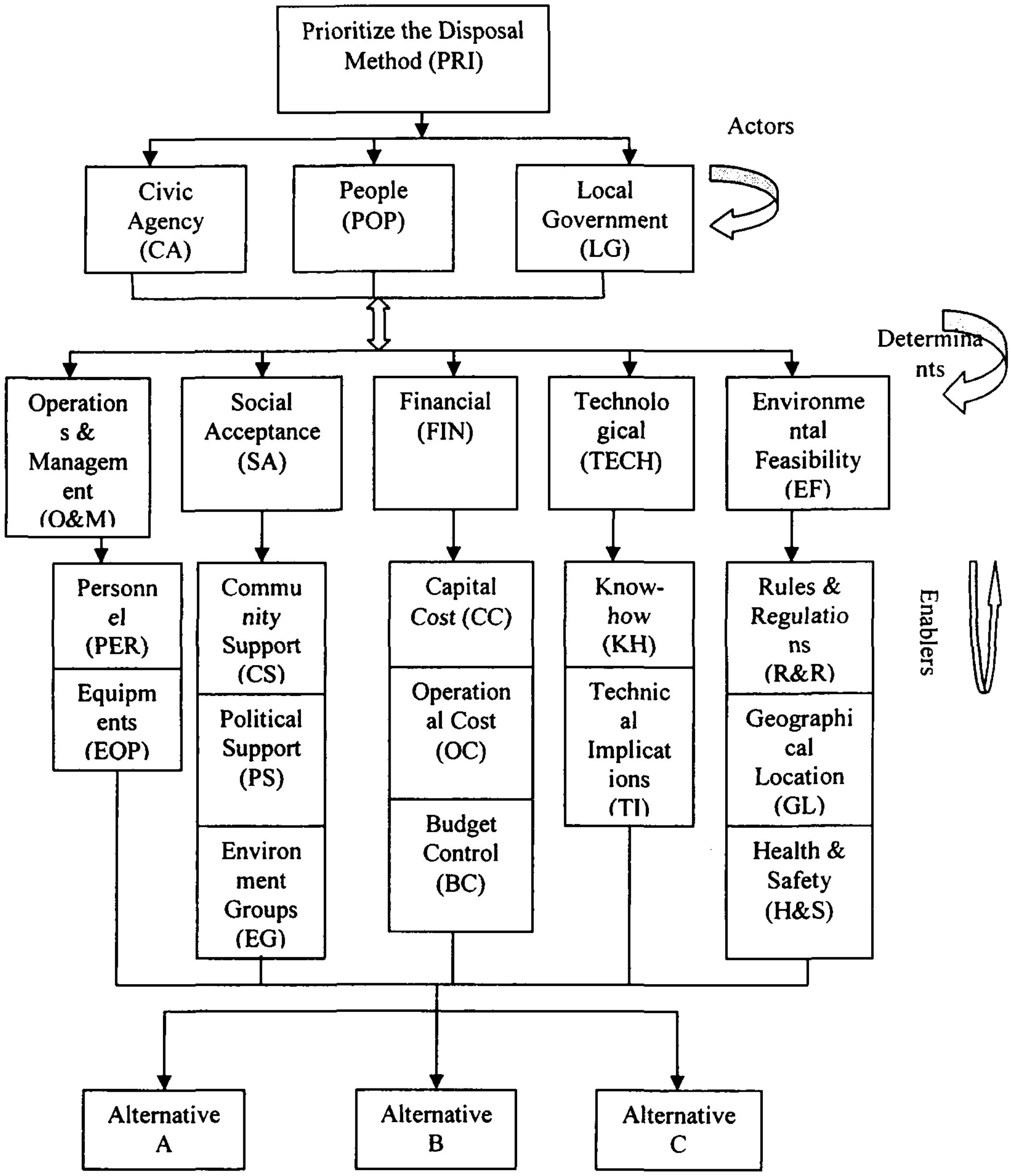


**Figure 4.1: ANP heirnet model for the selection of alternatives**

As shown in the Figure 4.1 the heirnet model, a two-way dependency or feedback occurs between the actors and the criteria. Also there is interdependence among the different enablers or the sub-criteria in the fourth level of the MSW heirnet.

### *4.5.4 Step II: Pair-wise Comparison*

A pair-wise comparison is the numerical representation of the relationship between two elements. It represents which element is more important to a higher criterion. Saaty (1980,1994) proposed a scale of 1-9, where 1 represents equally important, that is, the two elements contribute equally to the objective, while 9 represents extreme importance, that is favoring one element (row component) over another (column component). If the element has a weaker impact than its comparison element, the score range varies from 1, indicating indifference to 1/9, an overwhelming dominance by a column element over the row element. For reverse comparison of the elements the corresponding reciprocal value is assigned, so that the matrix $a_{ij}a_{ji}=1$.

To develop pair-wise comparison matrices, brainstorming session was conducted that included participants from all the three actors of MSWM as identified and shown in Figure 1. In addition to these actors, experts from academia and industry were also invited in the workshop to act as the moderators. Before the workshop, a brief outline of the decision model and literature related to MSWM and ANP was sent to 31 probable participants who had shown their willingness to attend the workshop. Finally, twelve participants from the three actors took part in the deliberations of the brainstorming session. The rest were unable to attend, with the majority citing the reason of prior engagements. The twelve participants included five from the civic agency, four from the people group and three from the local government. The participants were given the questionnaire, which consisted of the pairwise comparison among the various actors, determinants and enablers as delineated in the model. The final values for any pairwise comparison were selected on the basis of a consensus among the participants of the brainstorming session with the experts from industry and academia playing an active role to develop a consensus.

In this MSWM model there are about 31 pair-wise matrices. To be concise, limited numbers of pairwise matrices have been produced in the chapter. Table 4.5.3 delineates the pairwise comparison matrix of the criteria or the determinants under the parent node of civic agency along with the priority vector also known as eigen vector (e-vector) and the consistency ratio (CR). In this case the e-vectors were calculated using MS Excel.

**Table 4.5.3: Pair-wise comparison for determinants under actor civic agency**

| Civic Agency | O&M | SA | FIN | TECH | EF | e-vector |
|---|---|---|---|---|---|---|
| **Operations & Management (O&M)** | 1 | 1/4 | 1 | 1 | 1/3 | 0.101574 |
| **Social Acceptability (SA)** | 4 | 1 | 3 | 5 | 1 | 0.382509 |
| **Financial (FIN)** | 1 | 1/3 | 1 | 1 | 1/2 | 0.1177799 |
| **Technological (TECH)** | 1 | 1/5 | 1 | 1 | 1/3 | 0.0977787 |
| **Environmental Feasibility (EF)** | 3 | 1 | 2 | 3 | 1 | 0.30033 |

*CR: 0.011*

Table 4.5.4 represents the pair-wise comparison of the enablers under the determinant social acceptance. For the judgment to be acceptable the CR must be less than 0.1, as suggested by Saaty (1980); otherwise further study on the problem and re-evaluation of the pair-wise comparison is recommended.

**Table 4.5.4:Pair-wise comparison for enablers of the social acceptance under the actor civic agency**

| Social acceptance | Community support | Political support | Environmental groups | e-vector |
|---|---|---|---|---|
| **Community support** | 1 | 6 | 3 | 0.66667 |
| **Political support** | 1/6 | 1 | 1/2 | 0.11111 |
| **Environmental groups** | 1/3 | 2 | 1 | 0.22222 |

*CR: 0.00*

The final step in the pair-wise comparison is comparing the relative influence of the enablers on the alternatives. Table 4.5.5 depicts one such evaluation of alternatives for enabler political support in influencing the determinant social acceptance.

**Table 4.5.5: Pair-wise comparison of influence of enabler political support on the alternatives**

| Political Support | Alternative A | Alternative B | Alternative C | e-vector |
|---|---|---|---|---|
| **Alternative A** | 1 | 4 | 2 | 0.571429 |
| **Alternative B** | 1/4 | 1 | 1/2 | 0.142857 |
| **Alternative C** | 1/2 | 2 | 1 | 0.285714 |

#### *4.5.5 Step III: Super-Matrix Formation*

Table 4.5.6 shows the super-matrix after entering the prioritized values. Due to brevity, only the values of some major elements have been produced. The matrix is then raised to sufficiently large power until convergence occurs. More specifically, given that the super-matrix is irreducible, this involves raising the super-matrix to the power $2k+1$ and converges if $k \to \infty$ (Saaty, 1996; Meade and Sarkis, 1998). In the present study the convergence occurs at $M^{119}$.

**Table 4.5.6: Initial super matrix for MSW disposal options (Major Elements)**

| | PRI | CA | POP | LG | O&M | SA | FIN | TECH | EF |
|---|---|---|---|---|---|---|---|---|---|
| **CA** | 0.157596 | 0 | 0.285714 | 1 | 0.443316 | 0.166667 | 0.666667 | 0.666667 | 0.222222 |
| **POP** | 0.760789 | 0 | 0.571429 | 0 | 0.387479 | 0.666667 | 0 | 0 | 0.666667 |
| **LG** | 0.081615 | 1 | 0.142857 | 0 | 0.169205 | 0.166667 | 0.333333 | 0.333333 | 0.111111 |
| **O&M** | 0 | 0.101574* | 0.130148 | 0.07619 | 0 | 0.131544 | 0.75 | 0.75 | 0.203696 |
| **SA** | 0 | 0.382509* | 0.458991 | 0.391896 | 0 | 0.327524 | 0 | 0 | 0.266501 |
| **FIN** | 0 | 0.117799* | 0.05883 | 0.174515 | 0.5 | 0.115419 | 0 | 0.25 | 0.07666 |
| **TECH** | 0 | 0.097787* | 0.070249 | 0.140018 | 0.5 | 0.09799 | 0.25 | 0 | 0.122387 |
| **EF** | 0 | 0.30033* | 0.281783 | 0.217381 | 0 | 0.327524 | 0 | 0 | 0.330757 |
| **PER** | 0 | 0 | 0 | 0 | 0.666667 | 0 | 0 | 0 | 0 |
| **EQP** | 0 | 0 | 0 | 0 | 0.333333 | 0 | 0 | 0 | 0 |
| **CS** | 0 | 0 | 0 | 0 | 0 | 0.666667† | 0 | 0 | 0 |
| **PS** | 0 | 0 | 0 | 0 | 0 | 0.111111† | 0 | 0 | 0 |
| **EG** | 0 | 0 | 0 | 0 | 0 | 0.222222† | 0 | 0 | 0 |
| **CC** | 0 | 0 | 0 | 0 | 0 | 0 | 0.164008 | 0 | 0 |
| **BC** | 0 | 0 | 0 | 0 | 0 | 0 | 0.538988 | 0 | 0 |
| **OC** | 0 | 0 | 0 | 0 | 0 | 0 | 0.297004 | 0 | 0 |
| **KH** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 |
| **TI** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 |
| **R&R** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.428567 |
| **GL** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.142851 |
| **H&S** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.428582 |

* *e-vector from Table 4.4.3* † *e-vector from Table 4.4.4*

Table 4.5.7 shows the converged column stochastic matrix. The approach to arrive at a limiting super matrix is by taking repeatedly the power of the matrix, that is the original weighted super- matrix, its square, its cube, etc., until the limit is attained (converges) in which case the numbers in each row will all become identical.

**Table 4.5.7: Super matrix after convergence ($M^{119}$)**

| | PRI | CA | POP | LG | O&M | SA | FIN | TECH | EF |
|---|---|---|---|---|---|---|---|---|---|
| CA | 0.069764 | | | | | | | | |
| POP | 0.040622 | | | | | | | | |
| LG | 0.053697 | | | | | | | | |
| O&M | | 0.060738 | | | | | | | |
| SA | | 0.071205 | | | | | | | |
| FIN | | 0.046827 | | | | | | | |
| TECH | | 0.044799 | | | | | | | |
| EF | | 0.053009 | | | | | | | |
| PER | | | | | 0.01111 | | | | |
| EQP | | | | | 0.005555 | | | | |
| CS | | | | | | 0.024866 | | | |
| PS | | | | | | 0.124256 | | | |
| EG | | | | | | 0.062359 | | | |
| CC | | | | | | | 0.004756 | | |
| BC | | | | | | | 0.009116 | | |
| OC | | | | | | | 0.008988 | | |
| KH | | | | | | | 0.007093 | | |
| TI | | | | | | | | 0.007093 | |
| R&R | | | | | | | | 0.023603 | 0.023603 |
| GL | | | | | | | | 0.014876 | 0.014876 |
| H&S | | | | | | | | 0.022043 | 0.022043 |

## 4.6 DISCUSSION ON MODEL FOR SELECTION OF DIPOSAL OPTIONS FOR MSW

The public's approach towards solid waste facilities such as incinerators and landfills NIMBY, NOTE, LULU and BANANA (see Appendix) are crucial factors in determining waste management policy. The priorities obtained for the different elements clearly show that public support (0.124256) plays an important role in deciding the kind of disposal scheme that should be adopted. Social acceptance (0.071205) and civic agency (0.069764) are the other elements in the decision model that play an important role. This is reasonable as civic agency is the one that is entrusted with providing the sanitation and conservancy in the city. According to Garrod and Willis (1998), a SWM facility should be environmentally friendly, economically sound, and socially acceptable, and, if a SWM facility, as mentioned by Furuichi (1999), is not accepted, then it may be opposed, which may lead to social movements and conflicts between residents and authority. This may sometimes lead to closure of an existing facility or abandoning a comprehensive program of SWM, eventually leading to abysmal or total collapse of the SWM in an area. Petts (2000) states that "The most effective management of MSW has to relate to local environmental, economic and social priorities" and must go beyond the traditional consultative approaches that require the "expert" to draft the solution in advance of public involvement to a much more effective approach by involving the public before key choices have been made.

Thus, the ANP model presented in the chapter enables decision-makers to understand the various complexities of the problem of SWM and prioritize them in order to arrive upon an efficacious disposal method. Various disposal options were ranked on the basis of the different criteria in the model. Table 4.6.8 illustrates the priorities of the waste disposal option obtained by applying the analytic network process.

**Table: 4.6.8 Priorities of the three MSWM alternatives**

| Alternative | Normal | Ideal |
|---|---|---|
| Alternative A | 0.436298 | 1.0000 |
| Alternative B | 0.373555 | 0. 856192 |
| Alternative C | 0.190147 | 0. 435818 |

The results obtained clearly show that alternative A is the preferred option for disposal of waste. The combined use of the technologies of land filling and composting is the preferred method in India, followed by the waste disposal option B that is land filling, combustion and composting. The results also suggest that the waste segregation is a practice that should be adopted and adhered to in order to make MSWM highly effective. Though, waste segregation is being promoted in large metropolitan cities like Delhi, enough work is not being done in this direction in the other smaller cities and districts of the country.

India has several constraints like cost, waste characteristics and the social practices and inhibitions that impede municipalities in adopting the state-of- the- art technologies for SWM that are being used in the developed countries all over the world. Therefore, the second best option is alternative B, or the disposal of waste through land filling, composting and incineration. One of the major reasons for not utilizing the incineration as the waste disposal method is that the characteristics of waste in India are not suitable for combustion, as it constitutes around 60% (World Bank, 1999) of organic waste that is best suited for composting or disposing through land filling. Moreover, using combustion as a waste disposal method entails installing environmental control systems, the costs and complexities of which are equivalent to or even greater than the combustion system itself (Tchobanoglous et al., 1993). But since the experts, academics, officials and people residing in a metropolitan city were consulted alternative B came out to be as the second most preferred choice. The waste characteristics of the metropolitan cities are quite different from the rest of the country; for example, the compostable matter and moisture content are as low as 40% and 20% respectively (NEERI, 1999). The least preferred option obtained through the ANP heirnet model is alternative C (land filling), which is being ineptly practiced throughout the country. The un- segregated waste is used to fill up low lying areas or is being dumped in waste lands.

## 4.7 MODEL FOR SELECTION OF INFECTIOUS WASTE CONTRACTORS

### *4.7.1 Selection Criteria*

To comprehensively identify the factors required for the selection of contractors handling infectious waste a two way approach was taken. A thorough literature review was done and consultations with hospital managers, officials of municipalities and SWM experts were conducted. By this way finally 11 factors, shown in Table 4.7.9, were retained and grouped into three categories: equipment, qualifications and service capability.

**Table 4.7.9 Factors for selection of infectious waste contractors**

| Factors | Description | References |
|---|---|---|
| Container Storage | To provide storage to the total amount waste according to its categorization | Abdulla et al. (2008); Alagöz and Kocasoy (2008); Al-Wattar (2006); Pan and Chen (1997); Ruoyan et al. (2010) |
| Eliminate redundant use of machinery | The amount of waste that is recycled from the total waste generated | Alagöz and Kocasoy (2008); Hsiao et al. (2004); Qiu (2001) |
| MIS | Managing Information System | Alagöz and Kocasoy (2008); Askarian, Vakili and Kabir (2004); Yang et al. (2002) |
| Waste Discarded | Efficiently deal with the waste discarded | Abdulla et al. (2008); Alagöz and Kocasoy (2008); Ruoyan et al. (2010); Yang et al. (2002) |
| Environmental Standards | Conform to environmental standards | Ruoyan et al. (2010); Yang et al. (2002) |
| GPS | Provide GPS to standardize the transportation system | Alagöz and Kocasoy (2008); Chen (2000); Gu and Pan (1999) |
| Invoice Documentation | Provide correct invoice documentation | Chen (2000); Gu and Pan (1999); Ruoyan et al. (2010) |
| Additional Services | Provide additional services promptly | Siru, Pillay and Sinha (2006) Yang et al. (2002) |
| Appeal Process | Speed up appeal process | Chen (2000); Siru, Pillay and Sinha. (2006) |
| Program Alternatives | Clarify program alternatives | Fu (1998); Ruoyan et al. (2010); Siru, Pillay and Sinha. (2006) |
| Specialized Skills | Clarify specialized skills | Abdulla et al. (2008); Alagöz and Kocasoy (2008); Chung and Carlos (2003); Ruoyan et al. (2010); Yang et al. (2002) |

### *4.7.2 Analytic Network Model*

Procedure similar to the ANP model for selecting disposal option for MSW was adopted here in selection of infectious waste contractor. Informal discussions were carried out with the people, who were the major stake-holders such as hospital managers, municipality officials, experts in SWM and officials of the local environmental regulatory body.

### *4.7.3 Step I: ANP Model Construction*

*Infectious waste model*

The ANP model for the selection of the infectious waste contractor in this chapter consists of four levels as shown in Figure 4. 2. The first level is the decision problem of prioritizing the infectious waste contractors. The second level consists of three elements: contractor's equipment, contractor's qualification, and contractor's service capability. These are the main factors that influence the selection of the best available infectious waste management contractor. The third level consists of the enablers or the sub-criteria that support the determinants or the main factors in the second level. The last or the fourth level consists of the three different contractors that have to be evaluated through the ANP model based upon the collection of criteria.

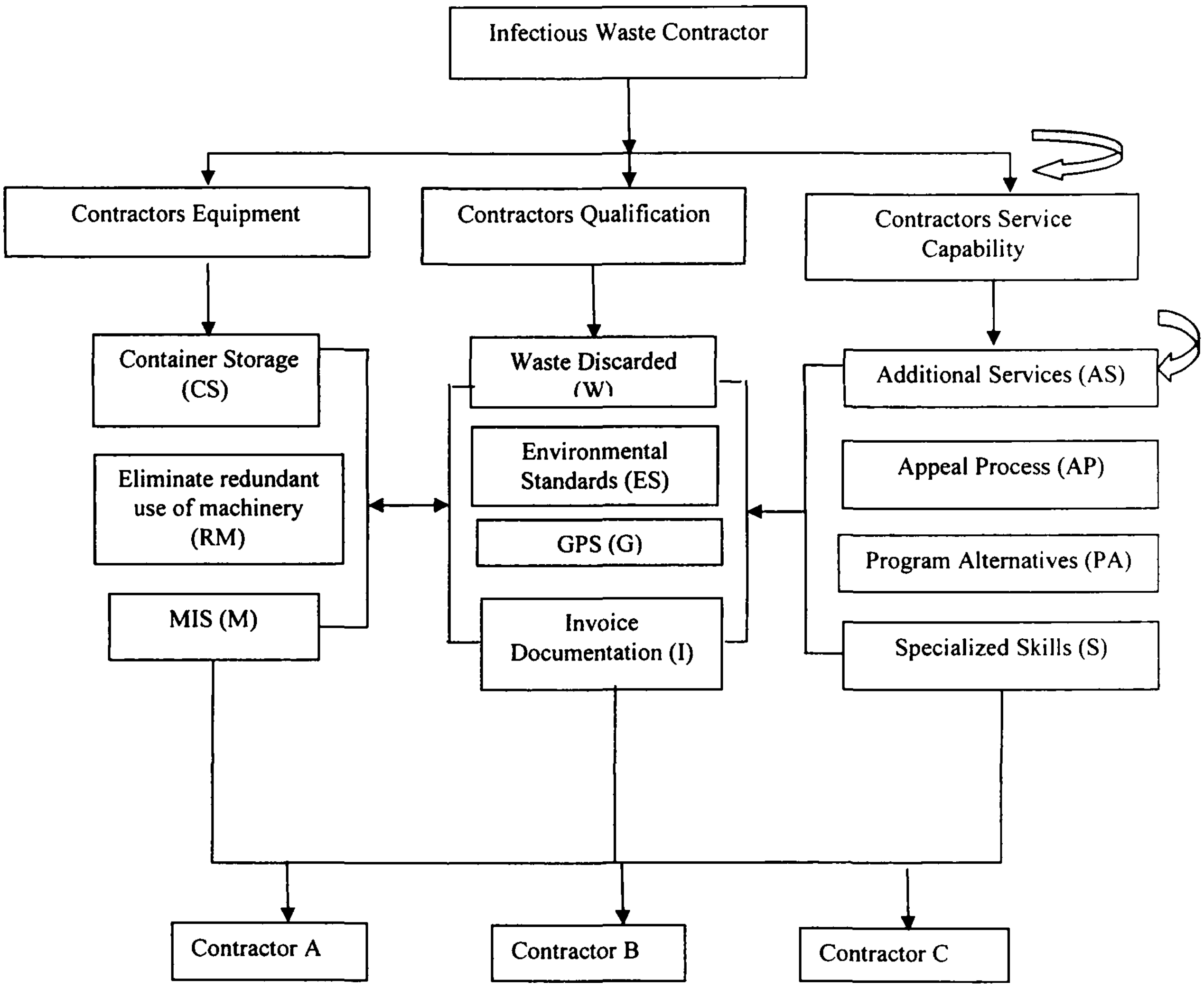


**Figure 4.2: ANP hiernet model for the selection of infectious waste contractors**

As shown in the Figure 4.2 of the heirnet model, there is interdependence among the different criteria and the sub-criteria in the second and the third level of the infectious waste heirnet model. Also, there is two- way dependency among the sub-criteria of the criteria contractors' equipment and qualification in the third level.

### *4.7.4 Step II Pair-wise Comparison*

A similar procedure to develop pair-wise comparison matrices was undertaken for the selection of the infectious waste contractors. Brainstorming sessions were conducted that included hospital managers, municipality officials, SWM experts, waste management firms and academia were invited as well. Only 10 participants out of the 22 invited took part in deliberations during the brainstorming session. The ten participants included five hospital managers, three municipality officials and two SWM experts. Same procedure as mentioned above for the MSW was adopted.

In this model there are about 29 pair-wise matrices. To be concise, limited numbers of pair-wise matrices have been reproduced in this chapter. Table 4.7.10 delineates the pair-wise comparison matrix of the containers equipment criteria or the determinants with it's enablers along with the priority vector, also known as eigen-vector (e-vector), and the consistency ratio (CR). The e-vectors in this case have been calculated using MS Excel©. For the judgment to be acceptable, the CR must be less than 0.1, as suggested by Saaty (1980); otherwise, further study on the problem and re-evaluation of the pair-wise comparison is recommended. The final step in the pair-wise comparison is comparing the relative influence of the enablers on the alternatives. Table 4.7.11 depicts one such evaluation of alternatives for enabler appeal process in influencing the determinant contractor's service capability.

**Table 4.7.10: Pair-wise comparison matrix for the contractor's equipment enablers**

| | (CS) | (RM) | (M) | e-vector |
|---|---|---|---|---|
| **Container Storage (CS)** | 1 | 3 | 1 | 0.428567 |
| **Redundant Machinery (RM)** | 1/3 | 1 | 1/3 | 0.142851 |
| **MIS (M)** | 1 | 3 | 1 | 0.428582 |

*CR=0.00*

**Table 4.7.11: Pair-wise comparison of influence of appeal process enabler on alternatives**

| | (A) | (B) | (C) | e-vector |
|---|---|---|---|---|
| **Contractor A (A)** | 1 | 4 | 2 | 0.571429 |
| **Contractor B (B)** | 1/4 | 1 | 1/2 | 0.142857 |
| **Contractor C (C)** | 1/2 | 2 | 1 | 0.285714 |

*CR=0.00*

### *4.7.5 Step III: Super-Matrix Formation*

Table 4.7.12 shows the super-matrix after entering the prioritized values. Due to brevity, only the values of some major elements have been produced. The matrix is then raised to sufficiently large power until convergence occurs. More specifically, given that the super-matrix is irreducible, this involves raising the super-matrix to the power $2k+1$ and converges if $k \to \infty$ (Saaty, 1996; Meade and Sarkis, 1998). The Table 4.7.13 shows the super-matrix for the infectious waste contractors; the convergence occurs at $M^{105}$.

**Table 4.7.12: Initial super matrix for selection of infectious waste contractors (major elements)**

| | EQ | QU | SC | AS | AP | PA | S |
|---|---|---|---|---|---|---|---|
| **CS** | 0.428567 | 0 | 0 | 0 | 0 | 0 | 0 |
| **RM** | 0.142851 | 0 | 0 | 0 | 0 | 0 | 0 |
| **M** | 0.428582 | 0 | 0 | 0 | 0 | 0 | 1 |
| **EQ** | 0 | 1 | 0.5 | 0 | 0 | 0 | 0 |
| **QU** | 1 | 0 | 0.5 | 0 | 0 | 0 | 0 |
| **SC** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **AS** | 0 | 0 | 0.216045 | 0 | 0 | 0 | 0 |
| **AP** | 0 | 0 | 0.508653 | 0.75 | 0 | 0 | 0 |
| **PA** | 0 | 0 | 0.160252 | 0.25 | 0 | 0 | 0 |
| **S** | 0 | 0 | 0.11505 | 0 | 0 | 0 | 0 |

**Table 4.7.13: Super-matrix after convergence for major elements (convergence occurs at $M^{105}$)***

| | CS | RM | M | EQ | QU | SC | AS | AP | PA | S |
|---|---|---|---|---|---|---|---|---|---|---|
| **CS** | 0.0213 | 0.0213 | 0.0213 | | | | | | | |
| **RM** | 0.0071 | 0.0071 | 0.0071 | | | | | | | |
| **M** | 0.0304 | 0.0304 | 0.0304 | | | | | | | |
| **EQ** | | | | 0.0038 | 0.0038 | 0.0038 | | | | |
| **QU** | | | | 0.0398 | 0.0398 | 0.0398 | | | | |
| **SC** | | | | 0.0358 | 0.0358 | 0.0358 | | | | |
| **AS** | | | | | | | 0.0079 | 0.0079 | 0.0079 | 0.0079 |
| **AP** | | | | | | | 0.0739 | 0.0739 | 0.0739 | 0.0739 |
| **PA** | | | | | | | 0.0539 | 0.0539 | 0.0539 | 0.0539 |
| **S** | | | | | | | 0.0644 | 0.0644 | 0.0644 | 0.0644 |

* *Values obtained are shown till four decimal places*

## 4.8 DISCUSSION ON MODEL FOR SELECTION OF INFECTIOUS WASTE CONTRACTOR

As discussed in the previous chapter decision making in the area of waste management in India has always been problematic. Generally, the decision makers take decisions without the help of the decision making tools resulting in waste problems and unsuccessful waste management programs. Selecting an appropriate infectious medical waste disposal contractor is often a subjective task. Especially in the medical sector, hospital managers lack precise and objective decision-making procedures and evaluation criteria. Moreover, planning a hospital waste management system is a very complex and difficult task since it requires dealing with the dynamic quality and quantity of waste. The improper management of infectious waste not only affects hospital occupants, but can pose a serious threat to the people in the vicinity of the health-care facility. Occupational health concerns exist for nurses, emergency medical personnel, and waste handlers. Hospital waste carries a higher potential for injury, infection and environmental pollution than any other type of health-care waste (WHO, 2001; 2004).

Therefore, integrating quantitative methods into the evaluation procedure enables decision makers to identify the most appropriate infectious medical waste disposal contractor objectively and efficiently.

The study proposes an analytic framework for the identification of factors and for selecting infectious waste handling contractors. The hierarchy has been developed by the help of existing literature and consulting experts, academia, and officials of the municipalities. The priorities obtained for different elements are presented in Table 4.7.13. Analysis of results indicates that the medical sector selects the most appropriate infectious medical waste disposal contractor based on the following rank: contractor's qualifications (0.039868), contractor's service capability (0.035865), and contractor's equipment (0.003875) respectively. According to the regulations in India, the hospital also has to take the legal responsibilities if the contractor improperly handles the medical waste. Therefore, while evaluating different contractors the hospitals should value the contractor's qualifications much more then its equipment and service capability factors.

Thus, the ANP model presented in the chapter enables decision makers to understand the various complexities of the problem of infectious waste management and prioritize them in order to select an efficacious contractor. Table 4.7.14 illustrates the priorities of the infectious waste contractors obtained by applying the analytic network process. The results show that contractor A is the most preferred followed by contractor C and the least preferred is contractor B.

**Table 4.7.14: Priorities of three infectious waste alternatives**

| Alternative | Ideal | Normal | Raw |
|---|---|---|---|
| **Contractor A** | 1.000000 | 0.412368 | 0.135980 |
| **Contractor B** | 0.480250 | 0.198039 | 0.065304 |
| **Contractor C** | 0.944770 | 0.389593 | 0.128469 |

These results were in tandem with the expectations of the professionals involved in the brainstorming sessions as some background information regarding the three contractors was provided to them initially.

The model was tested in 12 hospitals. However, in actual scenario, when the model was tested in the field the results were slightly different. The hospitals, which are entrusted with

the responsibility of disposing the infectious waste, selected contractor's qualification as the most important criteria followed by contractor's service capability. They gave the least importance to the contractor's equipment. This may be due to the fact that contractor's, who are in this business in an area use more or less same kind of equipments for storage, transfer and disposal of infectious waste. Hospitals wanted more readily appeal process, additional services and specialized skills from the contractor. The final result that came out after testing the model was that all of the 12 hospitals preferred contractor A the most. However, 8 out of 12 hospitals preferred contractor C as the second best alternative.
This chapter describes how the proposed method using ANP-based hiernet decision models could aid in the decision making process by explicitly considering the different types of dependencies in the decision structure by measuring the relative dominance of the criteria and alternatives. As per Saaty (2001), the AHP/ANP axiomatic foundation does not assume rationality, but assumes that thoughtful individuals who have reasons for their beliefs should make sure that their ideas are adequately represented in the model. Thus, the results obtained through the ANP methodology are in conformity with the view of the experts, working in the SWM and the hospital managers.

Segregation of municipal solid waste into bio-degradable and non-biodegradable is slowly gaining recognition in metropolitan areas, but waste segregation should be made mandatory not only in the large cities but also in the rest of the country. With the promulgation of the Bio-Medical waste Handling Rules (1998), hospitals are being stipulated to practice on-site segregation of the waste streams in to the infectious and non-infectious streams. Such measures would not only save the land that is being used as land fills, but will also mean less burden on the government exchequer, as the additional funds generated through the selling of compost would add to the revenue of the local municipalities. Above all, it will curtail the millions of rupees that are spent in buying land and constructing new land fills for disposal of municipal waste.

## 4.9 CONCLUSIONS

In a real scenario, waste management engineers and planners require tools that should produce efficacious results, are easy to use and comprehend, and which require moderate duration to arrive upon results. Therefore, in this chapter an attempt has been made

1. To develop a comprehensive methodology that incorporates diverse issues involved in prioritizing the disposal method of MSW and infectious waste management contractor.

2. To solve the problems of selecting the optimal disposal option for waste generated in a large city and selecting the best available infectious waste handling contractor in the chapter been solved through the flexible analytic network. ANP enables to break the problem into a systematic and logical way, which helps to comprehend the complexity of the problem.

3. To develop models that includes the interdependencies among various factors, which are often overlooked while making a decision. These are effectively captured and evaluated to arrive at a more transparent and logical conclusion.

ANP helps in arriving at a more holistic conclusion and provides an insight as to why a waste disposal alternative should be preferred. The proposed methodology may serve as a guideline to many of the solid waste management problems. Such models can be developed for various environment related problems, especially for various kinds of SWM, where adequate representation of all the stake-holders from diverse quarters can be effectively taken into account.

These results obtained in the selection of infectious waste management contractor can be useful to researchers, to the local authorities, hospital managers and others involved in the infectious waste management. Using this methodology and analysis would enable the managers at the health-care establishments to address the concerns of various stakeholders and take into account more environmentally sustainable policies in order to abide by the legislation. Regulations, legislation, and competitive pressures have made health-care organizations to function more environmentally sustainable. The method of selecting infectious waste contractors through the application of ANP helps in in-depth analysis of various technological or business decision alternatives. Thus, a systemic evaluation model to aid in accomplishing this task was introduced in this chapter.

The development of MCDM models such as ANP demands significant efforts and time from the decision-makers in evaluating various criteria and forming pair-wise comparison matrices. Also, such models are not universal as it may involve certain biases on part of decision-makers and human errors in understanding the basic difficulty, which may lead to skewed results and solutions.

The study presented in this chapter warrants further research by subjecting the model to sensitivity analysis. But the model presented here may serve as the reference point in evaluating the problems related to environmental issues. These results can be useful to researchers, to the local civic authorities and those involved in the infectious waste management. Although the proposed framework is for Indian scenario, this can be replicated for different countries. Another fact that this study can be done in fuzzy environment for additional model refinement and understand all the interdependencies etc among the factors. The analytic network process (ANP) (Saaty, 1996), the general form of AHP, is capable of handling interdependence among the elements by obtaining composite weights. This method has been recently developed to be used in fuzzy environment (Büyüközkan et al., 2004; Promentilla et al., 2008). Probably, it is a unique attempt to apply ANP in selecting an option for municipal waste disposal and infectious waste contractors. Further evaluation of the model and modification according to the individual needs by addition or deletion of certain elements in the models may prove beneficial in this field of study and would help in developing an intelligent system that would enable the decision- makers to arrive at a more scientifically and technically viable decision.

# CHAPTER 5

# EVALUATING PEOPLES ATTITUDES AND PARTICIPATION IN MUNICIPAL SOLID WASTE MANAGEMENT: A COMPARATIVE STUDY IN INDIA AND QATAR

## 5.1 INTRODUCTION

Municipal solid waste (MSW) generation continues to increase at an alarming rate world-wide. Governments are working towards tackling the problem of huge quantities of MSW generated by their population. One of the major problems facing a nation is the need for the proper disposal of the voluminous solid waste generated every year. In the industrialized nations, usually the quantity of waste and lack of disposal sites have been the causes of concern (Podar, 1993). In non-industrialized nations, on the other hand, the public's general lack of environmental knowledge and awareness, and the constant enlargement of areas of landfill disposal sites constitute major issues (Koushki and Alhumoud, 2002). In developing countries, like India and Qatar, there is growing concern among broad segment of the population for effective management of solid waste for different reasons and for its impacts on the day-to-day life of individuals and communities.

India is the second largest rapidly growing economy of the world and the second most populous country in the world as well. Due to huge population of over one billion, more than 90 percent of the MSW generated in India is unsatisfactorily managed (Das et al., 1998). This problem is acute in large cities as financial and technical facilities are inadequate to keep pace with the quantum of wastes generated. On an average 30 percent of solid waste of Indian cities is unattended by municipalities, which is generated in slum localities and other squatter settlements every day (Venkateswaran, 1994). It is primarily because of inefficiency and inability of the municipalities in extending MSWM to all the new areas mushrooming around the large cities. The existing MSWM plans were formulated without the adequate projection of growth in population in the years to come. Hence, the community bins that are installed at most of the places are inadequate for the number of people living in the area that they are intended to serve. The growing population and rising per capita consumption of goods and services are multiplying the generation of solid wastes, ranging from biologically and chemically active animal refuse and garbage to virtually inert glass and plastics. It is estimated that the per capita waste generation in urban areas, in India, with a population less that 0.1 million people, is 0.21 kg per day, while in areas with a population of more that 5 million people, it goes up to 0.5 kg per day, says a study by Ahmed and Jamwal (2000). Though the waste generated per capita in the developing countries is less than the developed *countries, still there is inadequate management of solid waste.*

Solid waste management (SWM) is an organized supervision of the generation, storage, collection, transport, separation, processing, recycling and disposal of solid wastes. Implementation of solutions to solid waste disposal problems requires strong engineering and organizational capacity. In developing countries the present scenario is grim, as there is lack of adequate long term planning and efficacious execution of the plans that are being formulated. Convenience and economic considerations are the priority over environmental considerations in every aspect of SWM. Therefore, in planning and implementing any MSWM plan, design and operation factors along with the health impacts on the population should be carefully considered. While discussing health aspects, Last (1986) argues that, the garbage component of solid wastes provides the maternity wards and free lunch counters for flies ad rats. In warm climates, exposed garbage has been found to produce as many as 70, 000 flies per $0.03m^3$ (1 $ft^3$) of garbage in a week. Therefore, improper and inadequate disposal of MSW is a potential threat to the millions of lives since it helps in spreading dangerous diseases like gastro-intestinal problems and parasitic diseases such as leptospirosis. Delhi is one of India's largest metropolitan cities and like other large cities faces similar problems of poor SWM.

In the state of Qatar the discovery of oil in the early sixties has resulted in the fast development of the cultural, infrastructural, and industrial aspects. It also, led to an increase in immigration to the area. A unique characteristic of Qatar is the constant change in the expatriate population from year to year. The generation and the characteristics of the urban solid waste are therefore in a process of constant change. Though Qatar is a small country compared to India, it doesn't battle either with land scarcity or high population density, but due to various industrial and infrastructural development that are taking place Qatar is facing a momentous problem of environmental degradation. According to a report by United Nations Industrial Development Organization in 2008, Qatar is ranked 4th among the world's top 10 offenders of ecosystem, preceded by UAE, USA and Kuwait. This conclusion is based on the calculation of the country's ecological footprint, which measures how much land and water area a human population requires to produce the resources it consumes and to absorb the waste it disposes under prevailing technology (UNEP, 2002). Therefore, Qatar needs managing its solid waste generated in harmony with the environment.

The primary focus of this paper is to analyze public attitudes towards participation in MSWM policies and programs in Doha and Delhi. Requisites for effective SWM are not only technical, fiscal, and political. Perceptions and behavioral approach towards solid waste per se of individuals and communities as a whole play important role in success of any SWM scheme. Also, this chapter proposes some feasible changes in the ways, which make MSWM efficacious on an individual or community level, so that there is overwhelming support for and compliance with MSWM projects.

## 5.2 MUNICIPAL SOLID WASTE MANAGEMENT IN DELHI AND DOHA

### *5.2.1 Municipal Solid Waste Management in Delhi*

Delhi is a large metropolitan city and the capital of India situated at 28°36'36"N 77°13'48"E. The city has an area of 1483 $km^2$ and is located on the banks of river Yamuna. Three local bodies: Municipal Corporation of Delhi (MCD), New Delhi Municipal Council (NDMC) and Delhi Cantonment Board (DCB) are entrusted with the SWM of entire Delhi. The largest is MCD with an area of 1397.30 $km^2$ to serve. The city of Delhi is divided into twelve administrative zones by MCD for efficient management of affairs. All operations of solid waste management (SWM) are carried by the Department of Environmental Management Services (DEMS) with the help of a staggering workforce of over 100,000. The services of DEMS include collection, transportation and disposal of MSW. An estimated 6300 tons per day of waste is handled by DEMS (TERI, 2001). Around 400 tons per day of waste is taken to three different compost plants in Delhi for processing and the rest is disposed in one of the three landfills located in North Delhi, East Delhi and South Delhi. The physical characteristics for the MSW of Delhi are given in Table 5.2.1. MCD spends about Rs 5030 million annually (USD 112 million approx.) on MSWM (MCD, 2005). Key issues for successful MSWM of Delhi are:

- Efficacious service delivery (swift collection and removal of garbage, leading to clean surroundings and feeling of well being amongst the citizens)
- Appropriate disposal of waste in conformity with the applicable environmental rules and most importantly,
- Strategy for reducing land requirement

**Table: 5.2.1 Composition of MSW in Delhi***

| Parameters | Percent by weight |
|---|---|
| Biodegradable | 38.6 |
| Paper | 5.6 |
| Plastic | 6.0 |
| Metal | 0.2 |
| Glass & Crockery | 1.0 |
| Non-biodegradable (leather, rubber, bones, and synthetic material) | 13.9 |
| Inert (stones, bricks, ashes, etc.) | 34.7 |

**Source: TERI (2002)*

Due to scarcity of appropriate land, the three landfill sites are being over-used. Delhi is in a grave situation as not many options are available for landfill siting within the city.

### *5.2.2. Municipal Solid Waste Management in Doha*

Doha is the capital of the state of Qatar situated at 25°17′12″N 51°32′0″E, with an area of 132 $km^2$. The latest estimate released puts the population of Qatar as 1.3 million (United Nations, 2008). About half of the total population of the country resides in the capital Doha. Qatar falls in the second place after Kuwait in the 'dumping of municipal waste' indicator, which is estimated 1.3 Kg/resident/day. The earlier estimates of the solid waste generated in the state of Qatar is 187,975 tons/year (Alhumoud, 2005). From the latest information collected it's calculated that the most recent figures for the generation of MSW are 475 kg/capita/year or 308,425 tons/year for the city of Doha. The estimate released by UNEP (2002) puts MSW generation as 430 kg/capita /day, which is a staggering, increase of 110 percent. The Ministry of Municipality Affairs and Agriculture (MMAA) is responsible for the management of MSW that is generated in the city of Doha. It manages its operations through the department called Baladiya. All solid waste generated is collected and disposed to the Umm Al-Afai landfill situated in west of Doha. At present no curbside recycling program is in place for the city of Doha, but the municipality manages a large composting plant since the eighties in Doha-Qatar. Some fractions of the waste, e.g., aluminum, paper, glass and plastics are collected and recycled in small recycling plants scattered in the region, that are mainly operated by the private sector. What obvious in this region are the lack of knowledge on the public's side and the lack of action by municipalities for implementing MSW recycling. Public interest and attitude is a key element in the success of any recycling program. The municipality will thus, need to offer the people a mechanism for sorting and recycling by implementing collection or bring systems (Alhumoud, 2005). However, recently an integrated solid waste management (ISWM) program has been placed for the city of Doha, which is scheduled to commence in the beginning of 2010. Through ISWM the amount of waste sent to the landfill will reduce drastically as the waste will be segregated for composting recycling, and incineration. Thus, extending the expected life of landfills and reducing the amount of land that needs to be set aside for future landfills. In the process, useful resources such as fertilizers and electricity will be produced. The physical characteristics of the MSW generated in Qatar are given in Table 5.2.2.

**Table 5.2.2: Estimated MSW composition of the state of Qatar***

| Constituents | Percentage |
|---|---|
| Organics | 57 |
| Paper | 18 |
| Plastics | 12 |
| Metals | 5 |
| Glass | 3 |
| Others | 5 |

**Source UNEP (2002)*

## 5.3 LITERATURE REVIEW

Problem of SWM is an amalgamation of various factors such as political, socio-cultural, technical, fiscal, and environmental factors (Khan and Faisal, 2008). MSWM decision making has undergone significant change in last 50 years spanning from 1960s. Earlier, the focus of the models varied from developing and optimizing collection routes and facility site selection, to developing sophisticated models with the aid of computers in the 1980s so that the cost of the mixed waste management is minimized (Gottinger, 1988). The early 1990s saw advent of the models that took in several factors and objectives Smith and Baetz (1991). SWM is an intrinsically complex problem, as it encompassed several objectives and difficulties (such as system's cost-benefit analysis, environmental considerations and technical) that are often in conflict with each other. Thus, models such as developed by Caruso et al. (1993), which is a multi-criteria decision making (MCDM) model, became *popular. MCDM enables choosing the best alternative by considering several criteria and is* being widely used in environmental problems. Many techniques such as AHP, ANP and fuzzy methods are available for solving environmental problems (Khan and Faisal, 2008; Karamouz et al., 2007; Partovi et al., 1990). Recently, models studying the societal acceptance, community and individual behavior and public participation in SWM programs have become popular.

There are numerous existing studies that provide a general understanding of the role and motives of people in the participation of SWM programs. The major factors for motivation of an individual to participate in SWM program may range from environmental altruism to economic rewards. Pro-environmental behavior (PEB) has led to significant waste control practices that have received noteworthy attention due to their importance for controlling waste proliferation and accumulation (Duncan, 1999; McKenzie-Mohr and Oskamp, 1995; Scott, 1999; De Young, 1991). According to DeYoung (1984), and Jacobs and Bailey (1982) people participated in MSWM for external rewards such as economic incentives in order to improve recycling and sorting (Refsgaard and Magnussen, 2009). However, these efforts are short lived since they cease to exist once the external rewards are withdrawn (Witmer and Geller 1976).

Demographics such as age, gender, income, social and occupational status, and educational level also play a crucial role in determining the extent and reasons for individuals to participate in MSWM (Corral-Verdugo, 2003). However, the impact of these factors is small (Hines et al., 1987). Older individuals recycle slightly more than young ones (Scott, 1999; Derksen and Gartrell, 1993), although the latter recycle more when they receive money in exchange for recycling products (De Young, 1991). Some studies point out that females recycle more than males (Stern et al., 1995). Level of household income certainly influences the extent of participation in MSWM. Higher the income the higher is the recycling effort (Derksen and Gartrell, 1993; Vining and Ebreo, 1990). Level of education also, makes people put in extra effort in sound MSWM practices such as waste minimization (Scott and Willits, 1994).

Factors such as social norms and concerns (Vining and Ebreo 1989), community involvement (DeYoung 1986), awareness about environmental issues (Katzev and Johnson, 1984) *and conservation ethic (Simmons and Widmar 1990) also encourage people to* participate in MSWM through waste control actions such as recycling, reuse, and reduced consumption. However, all these factors don't guarantee that an individual will take part in MSWM. The presence or absence of the infrastructure impacts one's decision to practice good conservation practices (Berger, 1997; Williams, 1991; Vining and Ebreo, 1990). Easy accessibility to recycling (Jacobs et al., 1984), knowledge about the logistics of recycling (e.g., what materials are recyclable, locations where materials can be taken) (Ebreo and Vining, 2000) and guarantee that the efforts of MSWM practices (such as recycling) being adopted would result in an improved environment (Refsgaard and Magnussen, 2009) influences a person's decision to adopt good MSWM practices. Therefore, spreading awareness and knowledge through media such as newspapers, magazines, television and radio (Lyons and Breakwell, 1994; Mainieri et al., 1997) about environmental conservation would induce waste control habits in children and adults as well.

## 5.4 METHODOLOGY

### *5.4.1 The Questionnaire*

Based on the literature review, informal discussion with experts in the SWM field and the officials of the bodies that manage MSW in the two cities and official environmental studies provided by the two civic bodies a questionnaire was constructed. It was modified according to the place where it was to be administered. Some of the questions of the two questionnaires are presented in the Table 5.4.3 and Table 5.4.4. The questions asked were about

- *Demographic information*: age, gender, marital status, education, monthly household income, family size
- *Attitudes to waste segregation (recycle)*
- *Attitudes to waste control*: the extent to which one engaged in a number of reuse, and reduced consumption.
- *Recycling motives.* Motives that represent both incentives and deterrents to waste segregation
- *Influence factors*: physical factors which may assist or inhibit waste segregation behavior.
- *Perceived control*: the individual's perception of their ability to perform the behavior, perception of the waste situation in the area in general
- *Consequences of waste segregation*

**Table 5.4.3: Some of the questions from questionnaire for city of Delhi (India)**

| |
|---|
| Do you segregate your household waste? |
| If Yes, then do you separate<br>1. Bio-degradable waste (such as kitchen waste)<br>2. Metals (such as iron, aluminum, steel etc.)<br>3. Glass<br>4. Paper & Cardboard<br>5. Plastics (such as bottles, cans, bags etc)<br>6. Any other? Please specify |
| If Yes, then why do you segregate?<br>• I make some money<br>• I care for environment<br>• I'm trying my bit to keep my surroundings clean (No litter)<br>• Saves energy<br>• I've strong interest in health of my family and my colony<br>• Any other reason? Please specify |
| If Yes, then how often do you segregate waste? |
| If No,<br>• Are you aware of the household waste segregation law?<br>• Would you segregate if adequate separate community bins are provided by the municipality?<br>• Would you segregate if assured that waste collected for recycling was actually recycled? |
| What are the major reasons, do you think make segregation a difficult proposition:<br>• Too busy<br>• No information about recyclables<br>• Requires to much time and effort<br>• Lack of storage space<br>• No separate recycling bins in my area |

| |
|---|
| • Any other? Please specify |
| Do you know waste segregation helps government save tax- payers millions in exchequer? |
| How much do you think is segregating waste economically valuable for the country? |
| How often do you<br>• Repair and re-use your items?<br>• Reuse containers?<br>• Change mobile phone?<br>• Buy rechargeable batteries?<br>• Buy refills?<br>• Buy long-life bulbs such as CFL?<br>• Use long-life carry-bags? |
| How often do you<br>• Use disposable items (such as paper cup, plates) at your work place?<br>• Look for 'energy star' in electrical/electronic goods when you buy?<br>• Buy recycled items?<br>• Look for environmentally friendly label when you buy?<br>• Look for the amount of packaging on products? |
| Would you be willing to pay for the waste that you throw? |
| What do you think about waste segregation for the preservation of environment? |
| What do you think about segregation of waste for the waste management in your city? |
| What do you think about the waste segregation law? |
| How willing are you to sensitize others about waste segregation? |
| Who do you think is responsible for managing the household waste generated? |
| How much are you satisfied with the services of the municipality in your area? |
| What are the major grievances that you have with the MCD?<br>• Over looking the public suggestions<br>• Poor quality of the services provided<br>• Lack of empathy and concern |

**Table 5.4.4: Some of the questions from questionnaire for the city of Doha (Qatar)**

| |
|---|
| Is your household waste segregated? |
| If Yes, then do you separate<br>1. Metals<br>2. Glass<br>3. Paper & Cardboard<br>4. Plastics<br>5. Any other? Please specify |
| If Yes, then why do you segregate?<br>• To donate<br>• I care for environment<br>• I'm trying my bit to keep my city clean (No litter)<br>• Saves energy<br>• Any other reason? Specify |
| How often do you recycle/ segregate waste? |
| If No,<br>• Did you recycle in your home country? (For expats)<br>• Would you segregate if made mandatory?<br>• Would you segregate if Ministry of Municipal Affairs and Agriculture (MMAA) introduces curbside recycling? |
| If No, then the reason<br>• No curbside recycling available<br>• I've no idea where the recycle facility is located<br>• No idea about the recyclables<br>• Too busy<br>• Too much effort and time required<br>• Lack of storage space<br>• Too dirty for me to do<br>• Any other? Please specify |
| Are you aware :<br>• Of curbside segregation in other GCC countries like UAE?<br>• That some communities (like Al-Khor community) in Qatar have curbside segregation in place? |
| Do you know MMAA can save millions by waste segregation? |
| How often do you<br>• Repair and re-use your items?<br>• Reuse containers?<br>• Change mobile phone?<br>• Buy rechargeable batteries?<br>• Buy refills?<br>• Buy long-life bulbs such as CFL?<br>• Use long-life carry-bags? |

| |
|---|
| How often do you<br>• Use disposable items (such as paper cup, plates) at your work place?<br>• Look for 'energy star' in electrical/electronic goods when you buy?<br>• Buy recycled items?<br>• Look for environmentally friendly label when you buy?<br>• Look for minimal packaging items? |
| How much do you think is segregating waste economically valuable? |
| Would you be willing to pay for the each bag of waste that you throw? |
| What do you think about waste segregation for the preservation of environment? |
| What do you think about segregation of waste for the waste management in your city? |
| Does waste segregation helps enhancing aesthetics? |
| How much do you think waste segregation is essential for preservation of environment? |
| How much do you think it will benefit making waste segregation mandatory? |
| How willing are you to sensitize others about waste segregation? |

Any SWM scheme is a success if it has public support and is socially accepted (Khan and Faisal, 2008). People play a significant role in the MSWM schemes. To evaluate the current status of the participation of people the questionnaires included questions on segregation of household waste into metals, glass, paper, cardboard, and plastics. A range of questions to assess attitudes, motives and factors influencing their participation in MSWM were asked. The participants to the survey were asked to assign a number on a 5-point scale, ranging from 1 'not important' to 5 'extremely important'. High numbers indicated a PEB.

### *5.4.2 Sampling Procedure*

The subjects studied were 205 individuals living in different areas falling under MCD authority in Delhi. The area of study selected was, where a pilot plan of MSWM was undertaken from the aid received from Japanese International Co-operative Agency (JICA). A final report was submitted to MCD in 2004. Around 360 families were contacted, which were selected randomly. 205 willingly took part in the door-to-door survey. 98 families were from low-income, 68 from middle-income, and 39 from high-income socioeconomic class neighborhood were interviewed, by trained interviewers. On an average three members of each family were interviewed (two adults and a juvenile under 18 years). These were the persons at home when the surveyors visited each household. A total of 178 females and 22 males were interviewed.

In the city of Doha out of 350 individuals 203 returned completed questionnaire, a response rate of 58%. Around 50% were expatriate, who had been living in the city for at least 2 years. The questionnaires were administered through emails and door-to-door survey. The sample included 137 females and 66 males. About 46 % of the respondents in the sample tended to be of relatively high socioeconomic status, with 84% holding a bachelors degree and 78% employed in professional or managerial positions. Lastly, 73% of the people in the sample surveyed lived in single family dwellings. Thus, it appears that respondents were primarily middle to upper class and well-educated.

## 5.5 RESULTS

A majority of the respondents in Delhi (52%) were graduates, and 41% were in middle class income category. The 18–30 and 30-45 age groups responded to the questionnaire in overwhelming numbers possibly because the surveyors were asked to direct the questionnaire to the person looking after the disposal of household waste. Therefore, majority of the respondents of the survey conducted were also females.

Majority of the sample indicated that they had segregated their household waste in the past, 95% stated that they recycled on a daily basis, and all agreed that they would recycle in the coming month. The overwhelming majority of respondents were, therefore, committed recyclers. This gave an indication that the questionnaire was completed by those, who were interested in environmental issues. To determine the factors that exerted the greatest influence on people for participating in MSWM multiple regression, as shown in Table 5.5, was used with willingness as the dependent variable.

However, in Doha majority of the people (73%) responded in negative to waste segregation. Most of the expatriates (88%), who responded, said that they recycled often in their home country. About 85% of the respondents reported that they are graduates.

According to the data collected in Doha, citizen's participation is not remarkably high, mainly due to absence of any comprehensive MSWM program. To determine, which factors exerted the greatest influence on recycling of people in Doha multiple regression was used, with recycling intention as the dependent variable. The following Table 5.6 gives the regression results.

### 5.5.1 Multiple regression

To determine which factors exerted the greatest influence on MSWM participation, in Delhi, multiple regression was used, with willingness to participate as the dependent variable. As shown in Table 5.5.5, factors perceived major components were entered. These components collectively explained 51.5 % of the variance in willingness to participate with consequences such as saving energy being statistically significant. Repair/reuse to reduce waste generation, positive perception towards MSWM and buying environmentally friendly items and absence of recycling bins being the statistically significant predictors. Factors such as buying refills and buying recycled items are driven by the need to being economical and not for the participation in MSWM per se. Consequences of recycling and concern for the community is other statistically significant, which depicts the PEB among the people.

Attitudes towards MSWM are significant predictors of success for the MSWM scheme in a given area; for the city of Doha they are given in the following Table 5.6.6. Eighteen factors were taken to understand the attitudes of the people in Doha towards MSWM. The variance in the attitudes is about 26.7%. Factors such as too busy, too much time and effort required, absence of curbside recycling, buying rechargeable batteries and minimal packaging were significant. However, the use of rechargeable batteries and looking for minimal packaging were not verily influenced by the concern for environment and waste minimization.

**Table 5.5.5: Multiple regression- willingness to participate in MSWM in Delhi**

| **Adjusted $R^2$ 0.515** | | | |
|---|---|---|---|
| | **Beta** | **t** | **Significant t** |
| Attitude | 0.211 | 3.720 | 0.000 |
| Repair/reuse | 0.044 | 3.673 | 0.000 |
| Reuse containers | 0.096 | 1.563 | 0.120 |
| Mobile phone change | 0.222* | 0.615* | 0.810 |
| Rechargeable Batteries | 0.029 | 0.351 | 0.726 |
| Refills | 0.099 | 1.686 | 0.003 |
| Buy CFLs | 0.166 | 2.693 | 0.016 |
| Use long-life carry bags | 0.081 | 1.087 | 0.279 |
| Use disposable items | 0.203* | 2.335* | 0.021 |
| Buy Energy star items | 0.267 | 2.490 | 0.014 |
| Buy recycled items | 0.174 | 2.448 | 0.005 |
| Look for Environment friendly items | 0.259 | 2.790 | 0.003 |
| Packaging amount on products | 0.089 | 1.345 | 0.180 |
| Preservation for environment | 0.006 | 0.087 | 0.931 |
| Consequences of recycling | 0.204 | 3.650 | 0.000 |
| Concern for community | 0.165 | 3.108 | 0.002 |
| Enhances Aesthetics | 0.143 | 1.788 | 0.076 |
| Lack of storage | 0.184 | 1.829 | 0.069 |
| Too dirty | 0.029 | 0.020 | 0.341 |
| Too busy | 0.016 | 0.031 | 0.659 |
| Too much effort | 0.037 | 0.062 | 0.231 |
| No idea about recyclables | 0.058 | 0.035 | 0.475 |
| Absence of recycling bins | 0.202* | 3.661* | 0.002 |
| Lack of recyclables | 0.198 | 1.765 | 0.008 |

Multiple regression calculates $R^2$, the proportion of the variance in the dependent variable accounted for by the independent variables. The statistical significance of this is tested by the $F$ ratio, and the model in this study was significant at the 99% confidence level. The relative contribution of each of the independent variables to explaining the variance in the dependent variable is determined by the beta weight. The variables whose beta weight has a significant $t$ of less than 0.05 are significant at the 95% confidence level. Any results that are statistically significant at the 95% confidence level are described as statistically significant within the text.

*Asterisks (*) show negative impact*

**Table 5.6.6: Multiple regression- willingness to participate in MSWM in Doha**

| **Adjusted $R^2$ 0.267** | | | |
|---|---|---|---|
| | **Beta** | **t** | **Significant t** |
| Too Busy | 0.245* | 2.314* | 0.002 |
| Effort and Time required | 0.196* | 2.857* | 0.005 |
| Storage Space | 0.022 | 0.234 | 0.815 |
| No curbside recycling | 0.327* | 2.431* | 0.000 |
| Too Dirty | 0.062 | 0.615 | 0.539 |
| Repair/Reuse | 0.095 | 0.788 | 0.432 |
| Change Mobile | 0.056* | 0.531* | 0.596 |
| Buy Rechargeable Batteries | 0.193 | 2.313 | 0.022 |
| Buy Refills | 0.121 | 1.800 | 0.074 |
| Use of Disposables | 0.027 | 0.289 | 0.773 |
| Energy Star Items | 0.007 | 0.078 | 0.938 |
| Recycled Items | 0.205* | 1.724* | 0.086 |
| Environmentally Friendly Labels | 0.122 | 1.430 | 0.155 |
| Minimal Packaging | 0.318 | 2.708 | 0.007 |
| Economically Valuable | 0.193* | 1.703* | 0.090 |
| Essential For Community Wellbeing | 0.151 | 1.710 | 0.089 |
| Enhance Aesthetics | 0.030 | 0.308 | 0.759 |
| Preservation of Environment | 0.086 | 0.810 | 0.419 |

Multiple regression calculates $R^2$, the proportion of the variance in the dependent variable accounted for by the independent variables. The statistical significance of this is tested by the $F$ ratio, and the model in this study was significant at the 99% confidence level. The relative contribution of each of the independent variables to explaining the variance in the dependent variable is determined by the beta weight. The variables whose beta weight has a significant $t$ of less than 0.05 are significant at the 95% confidence level. Any results that are statistically significant at the 95% confidence level are described as statistically significant within the text.

*Asterisks (*) show negative impact*

### 5.5.2 Correlation among the variables

Since the study on the attitudes of the denizens of the two countries included understanding waste minimization and recycling behavior, correlation was carried out to ascertain the influence of various factors among themselves. The following Table 5.5.7 gives an overview of the factors that are correlated with the attitudes towards participation in recycling and waste segregation.

**Table 5.5.7: Correlation between various factors for attitudes of people in Delhi towards MSWM**

| Attitudes | Correlation |
|---|---|
| Economic considerations | 0.455* |
| Energy saving | 0.312* |
| Clean surroundings | 0.421** |
| Enhance aesthetics | 0.221** |
| Preservation of environment | 0.345** |
| Lack of storage | 0.397* |
| Too dirty | 0.236 |
| Too busy | 0.063 |
| Too much effort | 0.111 |
| No idea about recyclables | 0.078 |
| Absence of recycling bins | 0.343* |
| Lack of recyclables | 0.329* |

*Significant at $P < 0.05$.
**Significant at $P < 0.01$.

The results suggest that waste segregation results in some economic benefit as the recyclables are sold off. Participation, also, enables in keeping the surroundings clean and enhancing the aesthetics of the area and thus, encourage people of the communities to participate in the recycling program. However, lack of storage and inadequate facilities such as absence of bins or inappropriate solid waste bins for recycling don't allow the people to participate effectively. Though the people in Delhi seemed to be overwhelmingly enthusiastic about participating in the municipal solid waste plan for their area, the absence of the adequate infrastructural facilities and lack of storage space in their homes deterred them to take part effectively. Moreover, people did cite lack of recyclables for their limited contribution, which is not due to ignorance about the recyclable items, as the majority (47%) of the people surveyed is from low-income strata.

**Table 5.5.8: Correlation between various factors for attitudes of people towards MSWM in Doha**

| Attitudes | Correlation |
|---|---|
| No curbside recycling | 0.194** |
| No idea of recycling facility | 0.076 |
| No idea about recyclables | 0.171* |
| Too busy | 0.200** |
| Too much effort | 0.314** |
| Lack of storage | 0.347* |
| Too dirty | 0.310** |
| Preservation of environment | 0.114 |
| Enhance aesthetics | 0.087 |
| Community wellbeing | 0.141* |
| Keeps city clean | 0.132* |
| Saves energy | 0.110 |

*Significant at $P < 0.05$.
**Significant at $P < 0.01$.

As shown in Table 5.5.8, perceived control like absence of curbside recycling, and the situational factors such as: recycling requires too much time and effort, requirement of too much storage space, were strongly correlated with recycling attitudes. This suggests: firstly, absence of the appropriate resources and opportunities to recycle contributes towards negative recycling attitudes of the respondents; secondly, that respondents in Doha feel that that recycling causes them inconvenience, takes up too much room or time, is too dirty and thus there is lack of recycling attitude among the people residing in Doha. However, the respondents indicated a remarkable extent of their agreement with concern for maintaining a good place to live and interest in the health and well-being of the community as it was also significantly correlated with recycling. Thus, the respondents, who were more likely, are concerned about environmental issues and the impact of waste on the environment and their communities are more likely to engage in MSMW. Therefore, it can be inferred that the people surveyed in Doha will overwhelmingly participate in the MSWM if an opportunity exists of doing so. However, preservation of environment, enhancement of aesthetics and energy saving were not significantly correlated with recycling. This indicates that though the respondents had strong and positive outlook regarding MSWM participation, they appeared to be less worried about the total scenario in general. A change in the attitudes of the people in Doha can be brought about if there is enough sensitization about the benefits of waste reduction and recycle.

### 5.5.3 Attitude and PEB through demographics

To determine whether specific sub-groups within the sample held significantly different views about waste minimization behavior, one-way ANOVA was used. The mean scores for each of the 12 waste minimization behaviors were compared by the demographic variables of age and gender.

**Table 5.5.9: Comparison of mean scores by age for the waste minimization variables for the city of Delhi**

| Age → / Variables | 18-30 Years | 30-45 Years | 45-65 Years | + 65 Years | F-ratio | P-value |
|---|---|---|---|---|---|---|
| Repair/ Reuse items | 4.00 | 3.51 | 3.23 | 3.19 | 10.923 | .000 |
| Reuse Containers | 4.00 | 3.93 | 3.89 | 3.82 | 1.387 | .248 |
| Change Mobiles | 1.00 | 1.52 | 1.48 | 2.85 | 34.498 | .000 |
| Buy Rechargeable batteries | 1.31 | 1.10 | 1.45 | 1.86 | 15.571 | .000 |
| Buy Refills | 3.92 | 3.70 | 3.65 | 3.86 | 2.409 | .068 |
| Buy CFLs | 2.91 | 2.21 | 2.21 | 2.08 | 2.719 | .046 |
| Use long-life bags | 3.55 | 3.04 | 2.58 | 2.08 | 10.861 | .000 |
| Use Disposable | 1.92 | 1.27 | 1.64 | 1.54 | 3.861 | .010 |
| Look for Energy Star | 1.69 | 1.44 | 2.01 | 3.64 | 32.501 | .000 |
| Buy recycled items | 2.77 | 2.85 | 2.41 | 1.55 | 17.604 | .000 |
| Look for Environmentally Friendly label | 1.46 | 1.33 | 1.70 | 1.82 | 4.924 | .003 |
| Packaging on the items | 1.55 | 1.15 | 1.21 | 1.08 | 6.276 | .000 |

The above Table 5.5.9 depicting the comparisons of mean scores by age indicates significant variation in ten out of the 12 waste minimization behaviors. The age groups of above 65 followed by 45-65 years are most likely to engage in minimizing waste. The only exceptions to this were buying goods labeled environmentally friendly, marked with energy star and buying rechargeable batteries. India being a developing country, the age group of above 65 practices waste minimization through point of purchase possibly due to the fact that most of the people in this age group have simple needs. Also, being the retired age group they have ample time to repair and reuse items for their basic needs. The age group least likely to engage in waste minimization behavior is the age group of 18-30 years.

**Table 5.5.10: Comparison of mean scores by age for the waste minimization variables for the city of Doha**

| Age → / Variables | 18-30 Years | 30-45 Years | 45-65 Years | + 65 Years | F-value | P-value |
|---|---|---|---|---|---|---|
| Repair/Reuse | 2.76 | 2.24 | 1.40 | 1.11 | 18.113 | .000 |
| Change Mobile Phones | 2.49 | 2.75 | 3.60 | 3.56 | 9.340 | .000 |
| Buy rechargeable batteries | 2.14 | 2.59 | 3.00 | 2.89 | 9.913 | .000 |
| Buy Refills | 2.50 | 2.61 | 2.93 | 2.44 | 1.675 | .174 |
| Reuse containers | 2.37 | 2.32 | 2.13 | 1.33 | 2.726 | .045 |
| Buy CFLs | 3.13 | 3.21 | 3.53 | 3.22 | 1.377 | .251 |
| Use life-long carry bags | 1.47 | 1.51 | 1.60 | 1.00 | 1.038 | .377 |
| Use disposable items | 2.09 | 2.45 | 2.53 | 3.11 | 6.574 | .000 |
| Look for energy star | 1.57 | 1.92 | 1.80 | 1.00 | 3.063 | .029 |
| Buy recycled items | 2.22 | 2.00 | 1.80 | 1.44 | 3.180 | .025 |
| Look for environment friendly | 2.23 | 2.47 | 2.33 | 2.11 | 1.160 | .326 |
| Look for packaging amount | 2.01 | 2.08 | 1.67 | 1.22 | 2.179 | .092 |

One-way ANOVA tests the null hypothesis that two or more samples drawn from the same population will have equal means. The procedure is based on the *F*-test which compares the between-groups variance with the within-groups variance, the larger the value of *F*, the more likely that the differences between groups are statistically significant. Where the *P*-value of *F* is less than 0.05, the null hypothesis is rejected, and the alternative hypothesis, that at least one group is statistically different from the others, is accepted the lower the mean score, the more likely that group of respondents will engage in the behavior.

The Table 5.5.10 above depicts the comparisons of mean scores by age; indicating significant variation in nine out of the 12 waste minimization behaviors. The findings of the waste minimization behavior in the city of Doha are quite similar to the findings for the city of Delhi. The age group of above 65 is the group that is most likely to engage in minimizing waste, through repair & reuse of the items or at the point of purchase. The only exceptions to this were buying goods labeled environmentally friendly and buying rechargeable batteries; possibly because the majority of people in this age group are likely to be unaware of the environment friendly items. The waste minimization through point of purchase is possibly due to the fact that most of the people in this age group have simple needs. Also, they have ample time to repair and reuse items for their basic needs. The age group least likely to engage in waste minimization behavior is the age group of 18-30 years. This, again, is likely to be due to time availability. This is confirmed by the comparison of mean scores by occupation. The respondents who stated that they were retired were more likely to engage in all the waste minimization behaviors (with the exception of buying rechargeable batteries) than all the other occupation groups.

Although the responses given are likely to bias the results, but the main intention behind the study is to investigate the real reasons for participating (or not participating) in waste segregation and minimization in the two cities of Delhi and Doha. Also, to understand the factors that influences the degree of participation of an individual in MSWM.

## 5.6 CONCLUSIONS

The study shows that the demographic characteristics of an individual had a little impact on their household waste management behavior. Mostly women were involved with the reuse and recycling at home, however, education level had little impact on the conservation practices. In view of the fact that India is a developing country with a per capita GDP of less that $5000 the driving force behind the waste minimization and recycling is economic. However, environmental altruism emerged as one of the drivers for waste control attitudes of the people. This provides some optimism for the success of environmental campaigns in developing countries like India and Qatar. The highlight of such campaigns should not only be disseminating environmental information but bringing about an attitudinal change among the targeted people.

In addition, the results seem to indicate that economic affluence decreases waste minimization attitude. People with higher household monthly income often changed their mobile phones, relied more on disposable items and repaired their things less compared to those who had less monthly household income. Also, the factors such as unavailability of economical labor for the repair of items influenced the decision of most of the people living in Doha. Therefore, minimization might be seen as a mere sign of frugality. Additionally, it was found that despite the ban on the use of plastic bags in Delhi, people across the strata of the society used them as they are given free in shops. Also, the people in Doha cared less for buying reusable bags being sold at large hypermarkets as using plastic bag for the goods is more convenient than remembering to carry the reusable bag from home. People in Delhi bought packaged items less compared to those in Doha as packaged products are expensive than buying loose products, thus confirming that waste minimization is done due to economic considerations.

The findings also suggest that the people of higher economic status participate more often in recycling as they had more opportunities (more objects, space, storage, and services) for doing it (Berger, 1997). Thus, it is not poverty itself the inhibitor of conservationism but its related situational variables (lack of space and consumed products and storage), which prevent people from more reuse and recycling (Corral-Verdugo, 2003). However, the outcomes of the study also tentatively suggest that waste control habits of an individual are influenced by the concern for environmental issues.

Furthermore, the results suggest that attitudes towards recycling determine the extent of ones recycling behavior. Also, the attitude towards recycling and waste control habits are controlled by the access of people to the proper infrastructure, having the basic knowledge about the MSWM participation, appropriate opportunities and above all an assurance that the efforts they are taking for MSWM participation are not going waste. It is often seen that an environmental program, requiring substantial people participation, turns futile despite efforts in promotion and spreading awareness. One of the major reasons is the lack of convenience, which diminishes the motivation of an individual to participate. People are likely to recycle more if curbside programs existed and if recycling required less preparation of the materials (Ebreo and Vining (2000). Past recycling practice and the well-being of the people in the neighborhood also played significant role in the MSWM participation.

Also, while conducting the study in Doha it came to light that landfill, a waste management alternative, is considered the most appropriate waste disposal technique in the Gulf region. Although, recently some countries in this region have placed recycling at the top of their waste management priorities, but the low cost of landfill due to the availability of land, setbacks the recycling programs. Therefore, an attitudinal change on the part of the people not only decides the participation in MSWM programs. The foremost requisite for any MSWM scheme is the presence of such a program itself. With the proper education and campaign programs, recycling at individual level could be started in the country.

Hence, this information can prove useful by making MSWM schemes more people friendly. The MSWM schemes can be formulated and implemented by incorporating the enablers such as: presence of curbside recycling, regular informational campaigns, and periodical feedbacks to the community regarding the success of the MSWM scheme. Concerted efforts should be made in minimizing the disablers (such as inconvenience) to encourage environmental conservation. The findings of this study suggest certain recommendations, which are presented in the next section.

## 5.7 RECOMMENDATIONS

Based on the findings of this research study the following recommendations are made:

1. A well coordinated and comprehensive MSWM program along with a public awareness program is necessary both for Doha and Delhi because of the highest per capita MSW generation rate and large population respectively.
2. Public awareness campaigns should target women particularly, since it appears that they are the ones dealing with the waste generated in the household.
3. Policy makers of the ISWM program should incorporate the convenience factor for the success of the MSWM scheme. Also, an assurance to the people about the targeted success is essential. Therefore, periodical outcome of the scheme should be delivered to the people.
4. The heterogeneous and changing population characteristic of Doha and burgeoning population of Delhi necessitates that estimation of the characteristics and the generation rates be reviewed at regular intervals of time.
5. An optimum frequency of the collection for the household waste should be assessed by the waste management authorities, especially in Delhi. An increase may have marginal effect on the increase of the amount of recyclables or waste, but will entail higher costs. However, a low frequency may risk the public health and the environment.

6. For handling the plastic bag waste, a drop off site should be made near the large hypermarkets in Doha, where the bags deposited could be taken for recycle by these hypermarkets or the waste management authority.
7. Awareness and information campaigns not only in academic institutions should be undertaken, but even in the places of work, so that the youth, particularly in the age group of 18- 30 years of age, can be roped in.
8. The dissemination of information about the minimization of waste should also be specific according to the vocation of the people targeted, so that they could make effective contribution to MSWM at their work places.

# CHAPTER 6

# INTERPRETIVE STRUCTURE MODEL FOR ANALYSIS OF ENABLERS AND BARRIERS IN SOLID WASTE MANAGMENT

## 6.1 INTRODUCTION

Waste management is one of the priority issues concerning protection of the environment and conservation of natural resources (Costi et al., 2004). Advances in environmental measurement techniques have shown that the current demand on the earth's resources is not sustainable and needs addressing immediately (York et al., 2004). In fact, municipal solid waste management (MSWM) one the most critical issues for the governments all over the world and the levels of concern and activity by citizens and governments world-wide has reached unprecedented levels in recent years (Read et al., 1997). In India factors such as rising consumer incomes, liberalization of economy, easy availability of credit from the banks, changing lifestyles has resulted in increased consumer spending and ultimately an increase in the amounts of household waste produced. The World Bank (1999) states that the problem of solid waste management (SWM) is beyond the ability of the municipal governments and they need assistance from the other levels of government, businesses and the general community to combat the problem of mismanagement of solid waste.

---

*A part of this chapter has been presented as:*

*'Analysis of interactions among the barriers to effective hospital waste management in India', (2008),* ***The 23rd International Conference on Solid Waste Management, Philadelphia, USA***

*A part of this chapter has been accepted for publication as:*

*'Analysis of interactions among the barriers to effective hospital waste management',* ***International Journal of Behavioural and Healthcare Research*** *(Inderscience Publication).*

World Bank further states that parts of India may face greatest waste management challenge in addition to other Asian countries; such as Indonesia, Philippines, and parts of China, since the projected waste generation rates and relative affluence may exacerbate the problem. Thus, ten years after the report proper disposal of municipal solid waste (MSW) is a cause for concern in India, because the management and control of MSW has been inadequate for years and management and disposal of municipal solid waste has never been under full control.

Solid waste management has evolved very significantly through the 20th century (Diaz and Warith, 2006). Municipal solid waste management (MSWM) involves activities associated with generation, storage, collection, transfer and transport, processing and disposal of MSW which is environmentally compatible, adopting principles of economy, aesthetics, energy and conservation. An efficacious SWM plan encompasses planning, organization, administration, financial, legal and engineering aspects involving an interdisciplinary relationship (Tin et al., 1995).

In India, municipal solid waste management (MSWM) is an obligatory function of urban local bodies and corporations. But this service is poorly performed by these agencies, which results in problems regarding health, sanitation and environmental degradation (Srivastava et al., 2005). Several case studies on MSWM in India have shown that the higher the average income of the people, the higher is their per capita waste generation (Srivastava et al., 2005). The generation of solid waste depends on the economy of a region. More prosperous the people are more the MSW is generated. It is reported by Visvanathan and Trankler (2003) that per capita generation increases with the level of income of the family or individual. Studies have indicated that for every Indian Rs. 1000 increase in income the solid waste generation increases by one kilogram per month. It is a common observation that with an increase of economic growth the waste generation grows in an equal manner. Growth and waste generation has not been decoupled in both the developing and the industrialized world.

Though there are several types of wastes like agricultural, industrial, civic amenity, household, commercial, and sewage waste, but for the purpose of this research only 'municipal solid waste (MSW)' is considered. MSW is mostly composed of domestic residues (Heinen, 1995) and the materials collected by the municipality, or by authorized organizations (Bruner and Ernst, 1986). According to the WHO (1999), MSW comprises of solid wastes generated from residential, commercial, industrial, institutional, construction, demolition, process, and municipal services. However, this definition varies greatly among waste studies, and some sources are commonly excluded, such as industrial, construction and demolition, and municipal services.

Solid waste generation depends on the economy of a region. More prosperous the people are more the MSW is generated. It is reported by Visvanathan and Trankler (2003) that per capita generation increases with the level of income of the family or individual. Studies have indicated that for every Indian Rs. 1000 increase in income the solid waste generation increases by one kilogram per month. It is a common observation that with an increase of economic growth the waste generation grows in an equal manner. Growth and waste generation has not been decoupled in both the developing and the industrialized world.

In urban centers, appropriate and safe SWM are of utmost importance to allow healthy living conditions for the population. This fact has been acknowledged by most governments; however, many municipalities are struggling to provide even the most basic services. Typically one to two thirds of the solid waste generated is not collected (World Resources Institute et al., 1996). As a result, the uncollected waste, which is often also mixed with human and animal excreta, is dumped indiscriminately in the streets and in drains, so contributing to flooding, breeding of insect and rodent vectors and the spread of diseases (CPCB, 2000; UNEP-IETC, 1996). Most of the municipal solid waste in low-income Asian countries, with GNI/capita of $975 or less (World Bank, 2008), which is collected, is dumped on land in a more or less uncontrolled manner. Such inadequate waste disposal creates serious environmental problems that affect health of humans and animals and cause serious economic and other welfare losses. All the mismanagement of solid waste occurs despite earmarking a staggering amount on SWM. Tin et al. (1995) report that solid waste management absorbed up to 1% of GNP and consumed about 20% to 40% of municipal revenues in developing countries.

The environmental degradation caused by inadequate disposal of waste can be expressed by the contamination of surface and ground water through leachate, soil contamination through direct waste contact or leachate, air pollution by burning of wastes, spreading of diseases by different vectors like birds, insects and rodents, or uncontrolled release of methane by anaerobic decomposition of waste. The insanitary landfilling of MSW causes emissions to occur during and after the landfill operation in the form of approximately 150 $m^3$ biogas/Mg MSW and 5 $m^3$/ha/day of leachate, depending on the waste composition and climatic conditions (Stegmann, 2002).

Globally, in 1985, 41% of the world population lived in urban areas, and by 2015 the proportion is projected to rise to 60 % (Schertenleib, 1992). Of this urban population 68 % will be living in the cities of low-income and lower middle-income countries. Since consumption is unstoppable and ever increasing, waste production is becoming gradually more important and its disposal is a problem that seriously threatens the sustainable development of society today (Benítez et al., 2008). The last 20 years, for example, has seen a substantial increase in the use of plastic packaging. Before this time many products such as foodstuffs were purchased loose or in reusable containers (Emery et al., 2007).

Thus, there is an urgent need to study exhaustively the variables that encourage effective MSWM, so that the world-wide menace of augmenting MSW could be tackled in order to diminish the environmental and health hazards. Moreover, understanding the various relationships among the variables, which aid sound MSWM, is essential so that the decision-makers in a SWM plan can take appropriate steps in formulating a plan and can arrive upon a more technically justifiable an environmentally sustainable plan.

Developing economies, such as India, have seen rapid industrial and economic advancements and urban growth coupled with manifold increase in population in the last two decades. These trends have also put health-care facilities under severe stress to meet the growing demand, leading to an increase in health-care waste generation. The waste generated from hospitals is now viewed as a serious health hazard in many countries (Gupta and Boojh, 2006). Hospital waste is generated during diagnosis, treatment and immunization processes in health-care establishments. It includes waste such as sharps, human tissue or body parts and other infectious materials (Baverja et al. 2000). These wastes can often be found dumped in domestic waste sites or even in rivers or canals near hospitals. Unintentional injuries may occur due to the exposure of improperly discarded sharps, leading to life-threatening infections such as Hepatitis B and C viruses and human immunodeficiency virus (HIV) (Franca et al., 2009). Improper disposal may also lead to the re-use of unsterilized syringes which results in 8-16 million Hepatitis B, 2.3-4.7 million Hepatitis C and 80,000-160,000 HIV infections annually (WHO, 2007). Uncontrolled burning of hospital waste pollutes the air with acidic gases, dioxins, furans, and heavy metals.

During the past few years, there has been an increase in public concern about the management of health-care waste on a global basis (Shinee et al., 2008) but in developing countries, hospital waste management have not received sufficient attention (Gupta and Boojh, 2006). In many countries, hazardous and medical wastes are still handled and disposed together with domestic wastes, thus creating a great health risk to municipal workers, the public and the environment (Da Silva et al., 2005). Improper disposal of wastes in hospitals places direct and indirect health impacts on those working in hospitals and the surrounding communities, and on the environment (Akhter and Trankler, 2003). Safe disposal of these wastes is an essential component in the maintenance of adequate hygiene standards, safe working conditions and effective risk reduction (Blenkharn, 2008). Despite the fact that current medical waste management practices vary from hospital to hospital, the problematic areas are similar for all health-care units and at all stages of management (Yong et al., 2009). Few studies can be found in literature that mentions the development of management schemes for hospital wastes (Karamouz et al., 2007).

Though, the available literature on hospital waste management describes the dependence of effective waste management in hospitals on the characteristics of some variables, the influence of interrelationships among these variables on the waste management effectiveness has been hardly taken into account. If not properly dealt with, these factors can significantly affect the overall effectiveness of the solid waste management system in hospitals. Therefore, there is a need to identify the barriers influencing the hospital waste management effectiveness and then to develop a generally applicable framework, which establishes interrelationships between these barriers. Further, a critical analysis of the variables affecting waste management in hospitals and their mutual interactions can be a valuable source of information for the decision-makers. Thus, it is important to understand their mutual relationships, so that those variables (called driving variables) which are at the root of some more variables and those (called driven variables), which are most influenced by the others is identified.

This chapter presents a new conceptual framework to understand the mutual relationships among variables classified as enablers or barriers. To date, there has been limited research undertaken in this area and so the findings should provide some directions to the agencies involved in MSWM and hospital waste management to evaluate and re-consider their methodologies.

Therefore, the main objectives are as follows:

1. to identify and rank the enablers and barriers to effective MSWM and hospital waste management respectively
2. to establish relationships among the identified variables using interpretive structural modelling (ISM) and
3. to enunciate the outcomes of the hierarchy based model developed in this research.

This chapter is further organized as: Section 6.2 briefly defines the municipal and hospital waste. Section 6.3 gives a concise modeling overview in solid waste management. It is followed by a section 6.4, which is development of the ISM model for the different enablers to MSWM. This section consists of the methodology of research in the sub-section on ISM methodology; subsequently sub-section 'matrix of cross impact multiplications applied to classification (MICMAC)' analysis of developed ISM model is presented to understand the driving power and dependence of these variables. Finally, the discussion about the outcomes from the model developed is given. The next section 6.5 consists of the model developed for barriers to the hospital waste management (HWM). The scheme of the model application and discussion is similar to the ISM model on MSW. The first sub-section delineates the barriers to the effective HWM. The next sub-section is about the application or the model development followed by MICMAC analysis of the ISM model. Discussion on the model is given in the last sub-section. The section 6.6 gives the conclusions for this work, followed by last section 6.7, limitations and scope for future research.

## 6.2 TYPES OF SOLID WASTE

### 6.2.1 *Municipal Solid Waste (MSW)*

WHO (1999), defines MSW as solid wastes generated from residential, commercial, industrial, institutional, construction, demolition, process, and municipal services. However, this definition varies greatly among waste studies, and some sources are commonly excluded, such as industrial, construction and demolition, and municipal services.

Solid waste management has evolved very significantly through the 20th century (Diaz and Warith, 2006). Municipal solid waste management (MSWM) involves activities associated with generation, storage, collection, transfer and transport, processing and disposal of MSW which is environmentally compatible, adopting principles of economy, aesthetics, energy and conservation. An efficacious SWM plan encompasses planning, organization, administration, financial, legal and engineering aspects involving an interdisciplinary relationship (Tin et al., 1995).

Though there are several types of wastes like agricultural, industrial, civic amenity, household, commercial, and sewage waste, but for the purpose of this research only 'municipal solid waste (MSW)' is considered. MSW is mostly composed of domestic residues (Heinen, 1995) and the materials collected by the municipality, or by authorized organizations (Bruner and Ernst, 1986).

In urban centers, appropriate and safe SWM are of utmost importance to allow healthy living conditions for the population. This fact has been acknowledged by most governments; however, many municipalities are struggling to provide even the most basic services. Typically, one to two thirds of the solid waste generated is not collected (World Resources Institute et al., 1996). As a result, the uncollected waste, which is often also mixed with human and animal excreta, is dumped indiscriminately in the streets and in drains, so contributing to flooding, breeding of insect and rodent vectors and the spread of diseases (CPCB 2000; UNEP-IETC and HIID, 1996). Most of the municipal solid waste in low-income Asian countries, with GNI/capita of $975 or less (World Bank 2008), which is collected, is dumped on land in a more or less uncontrolled manner. Such inadequate waste disposal creates serious environmental problems that affect health of humans and animals and cause serious economic and other welfare losses. The environmental degradation caused by inadequate disposal of waste can be expressed by the contamination of surface and ground water through leachate, soil contamination through direct waste contact or leachate, air pollution by burning of wastes, spreading of diseases by different vectors like birds, insects and rodents, or uncontrolled release of methane by anaerobic decomposition of waste. The insanitary landfilling of MSW causes emissions to occur during and after the landfill operation in the form of approximately 150 $m^3$ biogas/Mg MSW and 5 $m^3$/ha/day of leachate, depending on the waste composition and climatic conditions (Stegmann, 2002).

### 6.2.2 *Hospital Waste*

There is no universally accepted definition of "hospital waste". The terms medical wastes, hospital wastes and infectious wastes have often been used interchangeably, but hospital waste provides a broad definition and refers to all wastes generated by hospitals (Jang et al., 2006). In the direction to standardize waste classification, there are some efforts like European Union's '*Waste European Catalogue*'(Alvim-Ferraz and Afonso, 2003). The World Health Organization (WHO, 2007) has classified medical waste into different categories. These are:

- Infectious wastes: cultures and stocks of infectious agents, wastes from infected patients, wastes contaminated with blood and its derivatives, discarded diagnostic samples, infected animals from laboratories, and contaminated materials (swabs, bandages) and equipment (disposable medical devices etc.);
- Anatomic: recognizable body parts and animal carcasses;
- Sharps: syringes, disposable scalpels and blades etc;
- Chemicals: for example solvents and disinfectants;
- Pharmaceuticals: expired, unused, and contaminated; whether the drugs themselves (sometimes toxic and powerful chemicals) or their metabolites, vaccines and sera;
- Genotoxic waste: highly hazardous, mutagenic, teratogenic1 or carcinogenic, such as cytotoxic drugs used in cancer treatment and their metabolites;

- Radioactive matter, such as glassware contaminated with radioactive diagnostic material or radio-therapeutic materials; and
- Wastes with high heavy metal content, such as broken mercury thermometers.

In hospitals, procedures such as cobalt therapy, chemotherapy, dialysis, surgery, delivery, resection of gangrenous organs, autopsy, biopsy, para-clinical exams, injections, etc. results is the production of infectious wastes, sharp objects contaminated with patients' blood and secretions, radioactive wastes and chemical materials which are considered to be the hazardous wastes (Prüss et al., 1999). Inadequate management of this waste will cause environmental pollution, unpleasant smell, growth and multiplication of insects, rodents and worms and may also lead to the transmission of contagious diseases (Henry and Heinke, 1996).

Hospital waste generation depends on numerous factors such as number of beds, types of health services provided, economic, social and cultural status of the patients, established waste management methods, type of health-care establishment, hospital specializations, proportion of reusable items employed in health care, and proportion of patients treated on a day-care basis. It is now commonly recognized that certain categories of medical waste are among the most hazardous and potentially dangerous of all wastes generated in a community (Karademir, 2004).

As the volume and the complexity of health-care waste increase, the risk of transmitting disease through unsafe handling and disposal practices also increases. Globally, there has been an increase in the prevalence of highly communicable diseases such as AIDS and Hepatitis B and C, which amplifies the possibility of infection to the personnel handling hospital wastes, and the risks to public health arising from the transport of infectious and hazardous wastes (Almuneef and Memish, 2003). Also, in developing countries discarded plastics and sharps found in hospital waste can be easily sold and thus there is a potential for illegal reuse of used sharps, which cause a risk to the entire community (Ananth et al., 2010). There is growing awareness worldwide of the need to impose stringent measures on the handling and disposal of wastes generated by healthcare facilities. These would be in-line with the common concern for hospital hygiene and should form an essential part of hospital waste management.

## 6.3 MODELING APPROACHES IN SWM

A model is representation of an object, system or idea in some form, other than that of reality itself (Qureshi et al., 1999). Modeling is a tool used for the planning and management of municipal waste (Benítez et al., 2008). The use of mathematical models can be an alternative to deal with the problem of MSWM. Beigl et al. (2008) conducted a review of the literature regarding the models developed to estimate waste generation in order to classify the models according to the following criteria: regional scale, modeled waste streams, independent variables and method. In recent years, MSWM models have stressed "sustainability" and can be divided into two categories. One model category addresses social factors in the decision-making methods, whereas the other model incorporates public participation into the decision-making process (Hung et al., 2007).

Arey et al. (1993) applied a mixed optimization and probabilistic-analysis approach for determining daily waste management practices, Everett and Modak (1996) developed a model specifying the more convenient methods for MSW collection and disposal for each region, Huang et al. (1997, 1998) proposed interval-parameter programming techniques for planning solid waste management and capacity expansion. Chen and Chang (2000) formulated a grey fuzzy dynamic model for the prediction of solid waste generation.

Mathematical models are used to model solid waste management activities since 1980's (Su et al., 2008) like planning of solid waste management (Tanskanen and Melanen, 1999), integrated management of municipal waste (Fabricino, 2001), recovery of recyclable components (Jacobs and Everett, 1992), solid waste collection and transportation system in the city of Izmir, Turkey (Or and Curi,1993), problems of collection vehicles and traffic control (Chang et al., 1996), estimation of industrial and commercial waste generation in Vienna (Salhofer, 2000), transfer station locations in the MSW management system of Istanbul, Turkey (Kirca and Erkip, 1988)

Multi-objective programming is a popular method utilized to solve MSWM problems, such as locating sites, and choosing alternatives or strategies (Alidi, 1996; Chang and Wang, 1996). Analyses of the alternatives for final disposal in a sanitary landfill through a linear optimization model (Lund, 1990), cost-effective and workload-balancing operation in the regional solid waste-management system utilizing linear and integer programming methods (Chang et al., 1997), integer programming method to support the decisions of location and capacity for a material-recovery facility (Chang et al., 2005), grey integer programming-based game theory for system optimization and cost-benefit analysis at two competing landfills (Davila at al., 2005).

There are many researchers, who have carried out simulations and have modeled MSWM systems like MacDonald (1996b), who examined the state-of-the-art of solid waste (SW), analyzing 14 mathematical models based on economic optimization criteria. Fiorucci et al. (2003) developed a decision-support system (DSS) for SWM planning in the city of Genova, Italy. Simulation modeling, such as ORWARE (Eriksson et al., 2002) and EUGENE (Berger et al., 1999) has become popular in recent years. Barlishen and Baetz (1996) designed and developed a prototype decision support system to identify the activities and decisions required to conduct preliminary planning studies for MSW management systems.

## 6.4 METHODOLOGY FOR MODELING

To model the enablers for the successful MSWM and barriers to effective hospital waste management interpretive structural modeling (ISM) has been used. The ISM, as discussed in the section 2.3.3, is an interpretive methodology; the judgment of the group decides, whether and how the variables are related. It is structural too, as on the basis of relationship; an overall structure is extracted from the complex set of variables. The model so formed portrays the structure of a complex issue, a system of a field of study, in a carefully designed pattern employing graphics as well as words. The process of structural modeling consists of several elements: an object system, which is typically poorly defined system to be described by the model, a representation system, which is a well-defined set of relations and an embedding of perceptions of some relevant features of the object system into the representation system. Interpretation of the embedded object or representation system in terms of the object system results in an interpretive structural model (Sage, 1977). ISM has been applied by a number of researchers, as discussed in Table 2.3.3, to develop a better understanding of the systems under consideration. ISM is primarily intended as a group learning process, but it can also be used individually. The various steps involved in the ISM methodology are illustrated in Figure 6.1.

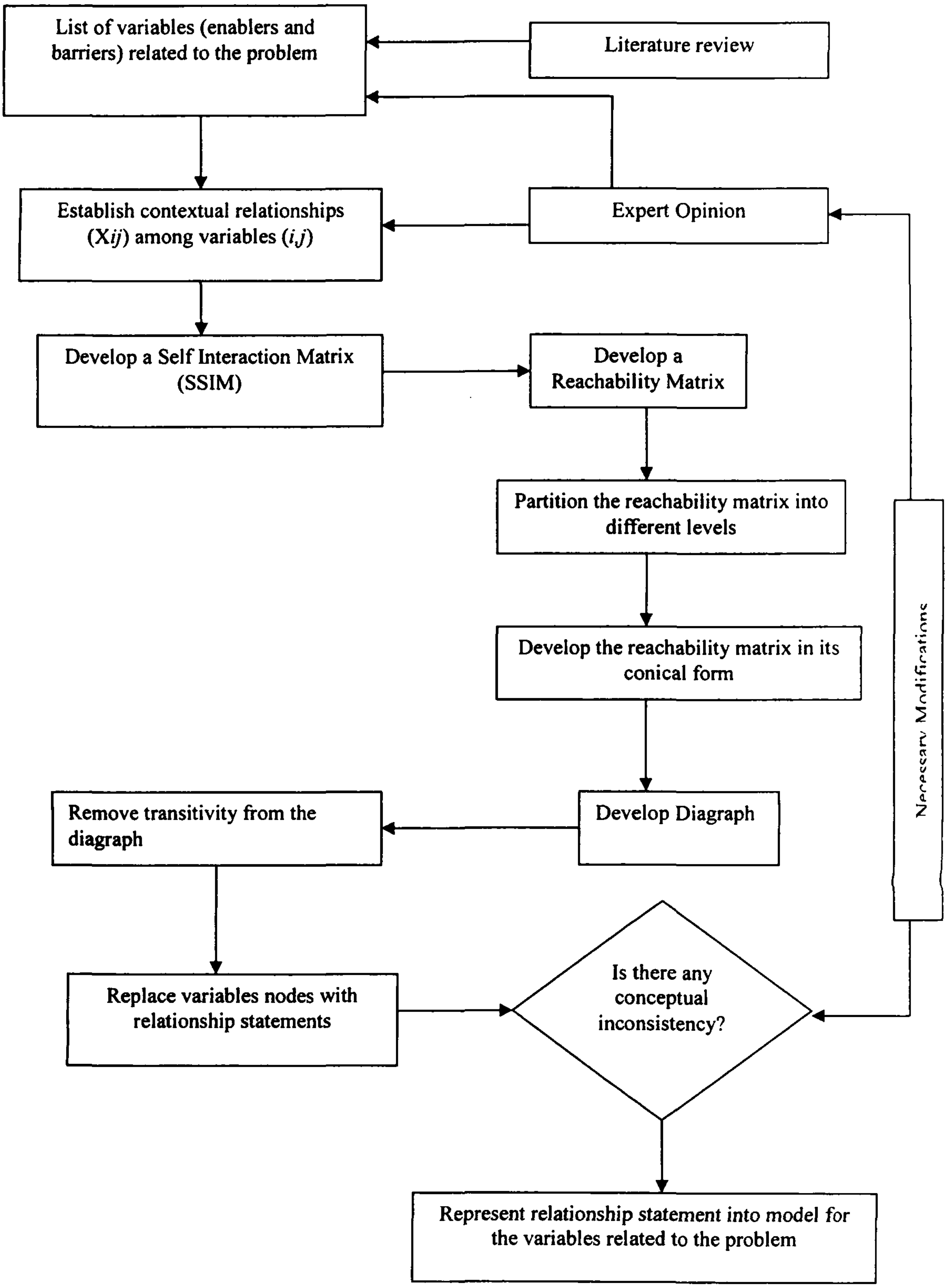


**Figure 6.1: Flow diagram for developing an ISM based model**

## 6.5 MODEL FOR THE ENABLERS OF MUNICIPAL SOLID WASTE MANAGEMENT

There are different variables in any management plan that may promote or hamper the implementation of the program. This section describes some of the enablers of the MSWM.

### *6.5.1 Enablers for Municipal Solid Waste Management (MSWM)*

After exhaustive literature review and discussion with the experts following thirteen variables were identified as the enablers to the effective MSWM.

*1. Regulatory framework:* Putting in place standards that would require businesses responsible for the waste they generate can be helpful in the reduction of waste. To try to combat the increasing levels of waste the European Union (EU) Landfill Directive was introduced in 1999, which set ambitious targets for the reduction of biodegradable municipal waste sent to landfill (Emery et al., 2007). Germany has implemented a mandatory recycling program in which, theoretically, the seller of consumer goods must take back all the package waste that is produced (Singhal and Pandey, 2001). In India, solid waste management services are provided by the civic bodies as per the provisions of the respective corporation/municipal/panchayat acts. Many of the acts are quite old and the provisions need amendments to reflect the changes in the waste management needs (Joseph, 2002). India lacks well formulated guidelines and policy structure regarding waste management services, in the absence of which the municipal agencies have not been performing their duties in this aspect satisfactorily (Gupta et al., 1998).

*2. Government/Private/NGO partnership:* Lack of public–private–government partnership is a major threat to a MSWM program (Srivastava et al., 2005). Thus, it is also necessary to harness and integrate the private sector, NGO's, and rag pickers into the overall institutional framework. The private sector is now becoming a key player in a number of industrialized nations. Private sector participation can help upgrade technical and managerial expertise, increase efficiency in operation & maintenance, and improve customer services, apart from bringing in the capital to support the government in its efforts at waste management (Singhal and Pandey, 2001). Non-governmental organizations can play an important role in effectively projecting the community's problems and highlighting its basic requirements for urban services. They could help in organizing the rag pickers into waste-management associations/groups under the supervision of the urban local body and the relevant residents' associations or market associations. Since poor conditions for temporary storage of wastes exist, NGOs in some areas have become involved in making arrangements for waste collection from households leading to improvement in local street cleanliness (Shekdar, 2009).

3. *Use of latest technology/ technology up gradation:* India has lagged behind in terms of adopting technologies for solid waste management (Singhal and Pandey, 2001). The equipment and machinery presently used in the system are usually of the type, which have been developed for general purpose or have been adopted from other industry. This results in under-utilization of existing resources and lowering of the efficiency.

4. *Public awareness/Community participation:* The problems of public participation in planning and implementation are no less important than the technical or economic aspects in waste management and decision-making (Joos et al., 1999). In a study by Srivastava et al. (2005) one of the major weaknesses of MSWM program was public apathy and community's non-willingness to cooperate and participate. To improve conservancy operations, authorities feel that the lack of civic awareness among city residents is proving to be a major hurdle to maintain the city clean. Even where storage arrangements are conveniently located, wastes tend to be strewn around the storage area, partly due to indiscipline and partly as a result of scavenging of the wastes by rag-pickers and stray animals (Joseph, 2002). Voluntary program of consumer education and business initiatives is the key to combat the apathy of the public and one of the tools to achieve this could be adoption of environmental management system (EMS), which is necessarily a voluntary initiative. The industries adopting EMS have achieved economic benefits also while achieving better environmental performance (Singhal and Pandey, 2001)

5. *Availability of finance:* In the Indian context, especially in the northern states, there is a lack of skills and awareness of the need to adopt proper MSWM services, resulting in inadequate allocation of financial and human resources by the government authorities and a

general public apathy (Raman, 1995). The limited revenues earmarked for the municipalities make them ill-equipped to provide for high costs involved in the collection, storage, treatment, and proper disposal of MSW. As a result, a substantial part of the MSW generated remains unattended and grows in the heaps at poorly maintained collection centres (Singhal and Pandey, 2001). A national policy and legislation for MSWM, titled the Municipal Solid Waste (Management and Handling) Rules, was notified in 2000, but most civic bodies are yet to take initiatives to comply with the rules citing financial constraints (Joseph, 2002).

6. *Proper transport:* Road conditions, traffic density and overall haul distance have a determining influence on vehicle choice. The density of traffic in any city or town will determine the speed of road traffic which, in turn will govern the type of vehicle most appropriate for the conditions (Tin et al., 1995). Different types of vehicles, varying from bullock carts to compactors, are used for waste transportation. However, the general-purpose open body trucks of 5 to 9 tones capacity are in common use. In smaller towns, tractor-trailers are used despite being noisy and inefficient. In a few cities, compactor vehicles are also being used. The waste is transported mostly by municipal vehicles; though, in some large towns, private vehicles are also hired to augment the fleet size. The maintenance of the vehicles is carried out in the general municipal workshop along with other municipal vehicles, where the municipal refuse vehicles receive the least priority. Most of these workshops have facilities for minor repairs only. Although preventive maintenance is necessary to maintain collection fleet in proper operating condition, neglect of preventive maintenance is a common situation. Transfer stations are in place only in a few metropolitan cities (Joseph, 2002). Due to shortage of financial resources, the vehicles are often used beyond their economical life resulting in inefficient operation. Selection of properly designed vehicles along with regular maintenance is important. Various factors like width of the road, transport volume, road conditions, etc. play important role in selection of vehicles. Proper garage should be provided to save the vehicles from wear and tear due to heat and rain.

7. *Waste disposal options:* In majority of urban centers in India, MSW is disposed by throwing away in the low-lying areas outside the city. These low-lying disposal sites, being devoid of a leachate collection system, landfill gas monitoring and collection equipment, can hardly be called sanitary landfills and are more in the nature of dumping sites. It would be

more worthwhile to adopt a scientific waste disposal system, in addition, to adequate collection system for complete management of waste. Landfills are the prime way of waste disposal in India, these needs to be designed with leachate collection and gas monitoring and collection system. The first step towards ensuring reduced land for waste disposal could be to increase the landfill depth to 9–10 m. This in addition would ensure that proper anaerobic degradation of the waste takes place so that the methane generated is large enough to be subsequently collected and used (Gupta et al., 1998).

*8. Metrics:* Metrics are required to in order to evaluate the environmental effects of a waste management system. Diaz and Warith (2006) have proposed waste analysis software tool for environmental decisions (WASTED), which relies on the life-cycle analysis (LCA) methodology to comprehensively evaluate the environmental effects of MSW management decisions. Integrated waste management model for municipalities (IWM), waste reduction model (WARM), developed by the US Environmental Protection Agency (USEPA), and the organic waste research (ORWARE) model, developed in Sweden by the Royal Institute of Technology (KTH) can be used to evaluate the waste management systems.

*9. Strategic planning:* The life cycle of the product ends with waste management, which includes recycling, composting and final disposal. At every stage of the life cycle there are emissions and consumption of resources. Efficient planning for municipal solid waste management systems requires accounting for the complete set of environmental effects and costs associated with the entire life cycle of MSW (Emery et al., 2007).

*10. Waste reduction at source:* Waste reduction at source can be accomplished in three ways: (1) fees and tax incentives to promote market-mechanisms to effect source reduction, (2) mandatory standards and regulations, and (3) education and voluntary compliance with policies by business and consumers (Singhal and Pandey, 2001).

*11. Segregation of waste:* In India waste segregation at source is rarely practiced (Joseph, 2002), though proper segregation would lead to better options and opportunities for scientific disposal of waste (Gupta et al., 1998). Segregation of waste at source into biodegradable and non-biodegradable components would not only reduce the cost of transportation for final disposal, but also provide segregated organic waste stock for waste to energy activities

(Singhal and Pandey, 2001). The study on physical composition municipal solid waste collected in some of the Indian cities by Kumar et al. (2004) reveals that the proportion of plastic and paper in waste generated are very significant and needs immediate attention in order to reduce environmental pollutants. Proper segregation of waste would lead to better options and opportunities for its scientific disposal. Recyclables for example, could be straightaway transported to recycling units, which, in turn, would pay the corporations for it, thereby increasing their income. Finally, the inert material that will be required to be sent to landfill would be of much lower quantity compared to un-segregated waste, consequently increasing the life of the existing disposal facilities.

*12. Proper collection mechanism:* A number of factors such as: waste generation rate, waste density, nature of the waste and transport condition have a direct bearing on the collection system and vehicle choice for any particular situation. In the absence of systematic solid waste collection systems, waste is dumped in open spaces, on access roads and along water courses (Tin et al., 1995). In spite of a stringent legislation in place, open dumping is the most wide spread form of waste disposal (Joseph, 2002). The preferred option would be to revamp the existing collection service structure to provide community with waste bins, conveniently placed for the people to deposit domestic waste, and door to door collection of waste. Properly designed collection bins and implements should be used for collection and storage of waste. Wastes should be collected frequently in order to avoid accumulation, which leads to degradation of environmental and aesthetic quality.

*13. Co-ordination between agencies involved in waste collection:* State-of-the-art schemes designed for the MSWM do not succeed in curbing the menace of the solid wastes if the various agencies involved fail to work in tandem. Lack of co-ordination among the agencies leads not only failure of the MSWM schemes, wastage of huge amounts of resources, but increases public apathy towards the mismanagement of the MSW.

### *6.5.2 Structural Self-Interaction Matrix*

For developing an ISM, participant response reflect judgement as to the existence of a relation between any two elements and the associated direction of the relation. If the relation holds from element *i* to element *j* and not vice-versa, the modeller or group responds with a V as symbolic of the direction from the upper element to the lower element. If the group perceives that the relation holds from element *j* to element *i* but not in both directions, the entry A is made as symbolic of the direction from the lower displayed element up to the upper displayed element. If the relation is perceived by the group as valid in both directions, it is represented by symbol X and lastly, if the relation between elements does not appear valid, the response symbol is O (Sage, 1977).

In this chapter, a contextual relationship of "alleviate" type is chosen to exist among the enablers for effective municipal solid waste management. This means that one variable tends to alleviate another variable. Based on this, contextual relationship between the variables is developed. Keeping in mind the contextual relationship for each variable, the existence of a relation between any two enablers (*i* and *j*) and the associated direction of the relation is questioned. Four symbols are used to denote the direction of relationship between the barriers (*i* and *j*):

V: Enabler *i* will alleviate Enabler *j*;

A: Enabler *j* will alleviate Enabler *i*;

X: Enabler *i* and *j* will alleviate each other; and

O: Enabler *i* and *j* are unrelated.

The following Table 6.5.1 would explain the use of the symbols V, A, X, and O in structural self interaction matrix (SSIM).

**Table 6.5.1: Structural self interaction matrix (SSIM) for MSWM enablers**

| $p_i$ → $p_j$ Enablers | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Use of latest technology | A | A | A | X | O | V | X | V | A | A | X | A |
| 2. Regulatory framework | X | X | V | V | V | O | V | V | V | V | V | |
| 3. Waste reduction at source | A | A | A | A | X | V | X | X | A | A | | |
| 4. Availability of funds | A | A | A | X | V | O | V | V | A | | | |
| 5. Co-ordination among agencies | A | A | X | V | V | V | V | V | | | | |
| 6. Segregation of waste | A | A | A | A | X | V | X | | | | | |
| 7. Proper collection mechanism | A | A | A | A | X | V | | | | | | |
| 8. Metrics/Benchmarks for MSWM effectiveness | A | A | A | A | O | | | | | | | |
| 9. Proper transport | A | A | A | A | | | | | | | | |
| 10. Waste disposal options | A | A | A | | | | | | | | | |
| 11. Strategic Planning | A | A | | | | | | | | | | |
| 12. Government/Private/NGO partnerships | X | | | | | | | | | | | |
| 13. Public awareness/ Community participation | | | | | | | | | | | | |

(i) Enabler 2 (regulatory framework) would alleviate enabler 11(strategic planning) hence the relationship is V (Table 6.5.1).

(ii) No direct relationship seems to exists between barrier 1 (Use of latest technology) and enabler 9 (proper transport) so the relationship is O (Table 6.5.1).

(iii) Enabler 3 (waste reduction at source) would be alleviate by enabler 13 (community participation). Increase in waste reduction at source means that more people are participating in the waste segregation, which entails that there is rise in the public awareness and participation of the people in a target area of the scheme; hence, the relationship between enabler 3 and 13 is A.

(iv) Enabler 6 (segregation of waste) and enabler 9 (proper transport) alleviate each other so the relationship is X

### *6.5.3 Reachability matrix*

The SSIM is transformed into a binary matrix, called the initial reachability matrix by substituting V, A, X, O by 1 and 0 as per the case. The rules for the substitution of 1's and 0's are the following:

1. If the (*i*, *j*) entry in the SSIM is V, then the (*i*, *j*) entry in the reachability matrix becomes 1 and the (*j*, *i*) entry becomes 0.

2. If the (*i*, *j*) entry in the SSIM is A, then the (*i*, *j*) entry in the reachability matrix becomes 0 and the (*j*, *i*) entry becomes 1.

3. If the (*i*, *j*) entry in the SSIM is X, then the (*i*, *j*) entry in the reachability matrix becomes 1 and the (*j*, *i*) entry also becomes 1.

4. If the (*i*, *j*) entry in the SSIM is O, then the (*i*, *j*) entry in the reachability matrix becomes 0 and the (*j*, *i*) entry also becomes 0.

Following these rules and after incorporating the transitivities (employing the transitivity principle that if variable A is related to B and B is related to C, then A is necessarily related to C) the final reachability matrix is shown in Table 6.5.2. In Table 6.5.2, the driving power and the dependence of each enabler are also shown. The driving power for each enabler is the total number of enablers (including itself), which it may impact. Dependence is the total number of enablers (including itself), which may be impacting it. These driving power and dependencies will be used in MICMAC analysis, where the enablers will be classified into four groups of autonomous, dependent, linkage, and independent (driver) enablers.

**Table 6.5.2: Final reachability matrix for the enablers for MSWM**

| $p_j$ → / $p_i$ ↓ Enablers | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | Driving power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Use of latest technology | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1* | 1 | 0 | 0 | 0 | 8 |
| 2. Regulatory Framework | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 13 |
| 3. Waste reduction at source | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 5 |
| 4. Availability of funds | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1* | 1 | 1 | 0 | 0 | 0 | 8 |
| 5. Co-ordination among agencies | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 10 |
| 6. Segregation of waste | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 5 |
| 7. Proper collection mechanism | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 5 |
| 8. Metrics/Benchmarks to quantify MSWM effectiveness | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| 9. Proper transport | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 5 |
| 10. Waste disposal options | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 8 |
| 11. Strategic Planning | 1 | 0 | 1* | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 10 |
| 12. Government/Private/NGO partnerships | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 13 |
| 13. Public awareness/ Community participation | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| Dependence | 8 | 3 | 12 | 8 | 5 | 12 | 12 | 13 | 12 | 8 | 5 | 3 | 3 | |

**Transivitive links*

### *6.5.4 Level partitions*

From the final reachability matrix, the reachability and antecedent set for each enabler are found (Sage, 1977). For every element $p_i$, the reachability set $R(p_i)$ is defined as the set of elements reachable from $p_i$. $R(p_i)$ may be determined by inspecting the row corresponding to $p_i$, the element that column represents is contained in $R(p_i)$. Similarly, for every element $p_j$, an antecedent set $A(p_j)$ is defined, which is the set of elements which reach $p_j$. $A(p_j)$ may be determined by inspecting the column corresponding to $p_j$. For every row, which contains a 1 in column $p_j$, the element that row represents is contained in $A(p_i)$.

The elements in the top level of the hierarchy will not reach any elements above their own level. As a result, the reachability set for a top-level element $p_i$ will consist of the element itself and any other elements within the same level, which the element may reach, such as components of a strongly connected subset. The antecedent set for a top-level element will consist of the element itself, elements which reach it from lower levels, and any elements of a strongly connected subset involving $p_i$ in the top level. As a result, the intersection of the reachability set and the antecedent set will be the same as the reachability set if $p_i$ is in the top level. Note that if the element in question were not a top-level element, the reachability set would include elements from higher levels, and the intersection of the reachability and antecedent sets would differ from the reachability set. Therefore, an element $p_i$ is top-level element if

$$R(p_i) = R(p_i) \cap A(p_i)$$

Once the top-level element is identified, it is separated out from the other elements. Then, the same process is repeated to find out the elements in the next level. This process is continued, as shown in Table 6.5.3, until the level of each element is found. These levels help in building the digraph and the final model.

**Table 6.5.3: Iterations for enablers of MSWM**

| **Enabler** $p_i$ | **Reachability set** $R(p_i)$ | **Antecedent set** $A(p_i)$ | **Intersection set** $R(p_i) \cap A(p_i)$ | **Level** |
|---|---|---|---|---|
| 1 | 1,3,4,6,7,8,9,10 | 1,2,4,5,10,11,12,13 | | |
| 2 | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 2,12,13 | | |
| 3 | 3,6,7,8,9 | 1,2,3,4,5,6,7,9,10,11,12,13 | | |
| 4 | 1,3,4,6,7,8,9,10 | 1,2,4,5,10,11,12,13 | | |
| 5 | 1,3,4,5,6,7,8,9,10,11 | 2,5,11,12,13 | | |
| 6 | 3,6,7,8,9 | 1,2,3,4,5,6,7,9,10,11,12,13 | | |
| 7 | 3,6,7,8,9 | 1,2,3,4,5,6,7,9,10,11,12,13 | | |
| 8 | 8 | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 8 | I |
| 9 | 3,6,7,8,9 | 1,2,3,4,5,6,7,9,10,11,12,13 | | |
| 10 | 1,3,4,6,7,8,9,10 | 1,2,4,5,10,11,12,13 | | |
| 11 | 1,3,4,5,6,7,8,9,10,11 | 2,5,11,12,13 | | |
| 12 | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 2,12,13 | | |
| 13 | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 2,12,13 | | |
| **Iteration ii** | | | | |
| 1 | 1,3,4,6,7,9,10 | 1,2,4,5,10,11,12,13 | | |
| 2 | 1,2,3,4,5,6,7,9,10,11,12,13 | 2,12,13 | | |

| Enabler $p_i$ | Reachability set $R(p_i)$ | Antecedent set $A(p_i)$ | Intersection set $R(p_i) \cap A(p_i)$ | Level |
|---|---|---|---|---|
| 3 | 3,6,7,9 | 1,2,3,4,5,6,7,9,10,11,12,13 | 3,6,7,9 | II |
| 4 | 1,3,4,6,7,9,10 | 1,2,4,5,10,11,12,13 | | |
| 5 | 1,3,4,5,6,7,9,10,11 | 2,5,11,12,13 | | |
| 6 | 3,6,7,9 | 1,2,3,4,5,6,7,9,10,11,12,13 | 3,6,7,9 | II |
| 7 | 3,6,7,9 | 1,2,3,4,5,6,7,9,10,11,12,13 | 3,6,7,9 | II |
| 9 | 3,6,7,9 | 1,2,3,4,5,6,7,9,10,11,12,13 | 3,6,7,9 | II |
| 10 | 1,3,4,6,7,9,10 | 1,2,4,5,10,11,12,13 | | |
| 11 | 1,3,4,5,6,7,9,10,11 | 2,5,11,12,13 | | |
| 12 | 1,2,3,4,5,6,7,9,10,11,12,13 | 2,12,13 | | |
| 13 | 1,2,3,4,5,6,7,9,10,11,12,13 | 2,12,13 | | |
| **Iteration iii** | | | | |
| 1 | 1,4,10 | 1,2,4,5,10,11,12,13 | 1,4,10 | III |
| 2 | 1,2,4,5,10,11,12,13 | 2,12,13 | | |
| 4 | 1,4,10 | 1,2,4,5,10,11,12,13 | 1,4,10 | III |
| 5 | 1,4,5,7,10,11 | 2,5,11,12,13 | | |
| 10 | 1,4,10 | 1,2,4,5,10,11,12,13 | 1,4,10 | III |
| 11 | 1,4,5,10,11 | 2,5,11,12,13 | | |
| 12 | 1,2,4,5,10,11,12,13 | 2,12,13 | | |
| 13 | 1,2,4,5,10,11,12,13 | 2,12,13 | | |
| **Iteration iv** | | | | |
| 2 | 2,5,11,12,13 | 2,12,13 | | |
| 5 | 5,11 | 2,5,11,12,13 | 5,11 | IV |
| 11 | 5,11 | 2,5,11,12,13 | 5,11 | IV |
| 12 | 2,5,11,12,13 | 2,12,13 | | |
| 13 | 2,5,11,12,13 | 2,12,13 | | |
| **Iteration v** | | | | |
| 2 | 2,12,13 | 2,12,13 | 2,12,13 | V |
| 12 | 2,12,13 | 2,12,13 | 2,12,13 | V |
| 13 | 2,12,13 | 2,12,13 | 2,12,13 | V |

### *6.5.5 Building the ISM-based model*

From the final reachability matrix depicted in Table 6.5.3, the structural model is generated by means of vertices or nodes and lines of edges. If there is a relationship between the barriers $j$ and $i$ this is shown by an arrow which points from $i$ to $j$. This graph is called a directed graph or digraph. After removing the transitivities, the digraph is finally converted into ISM as shown in Figure 6.2.

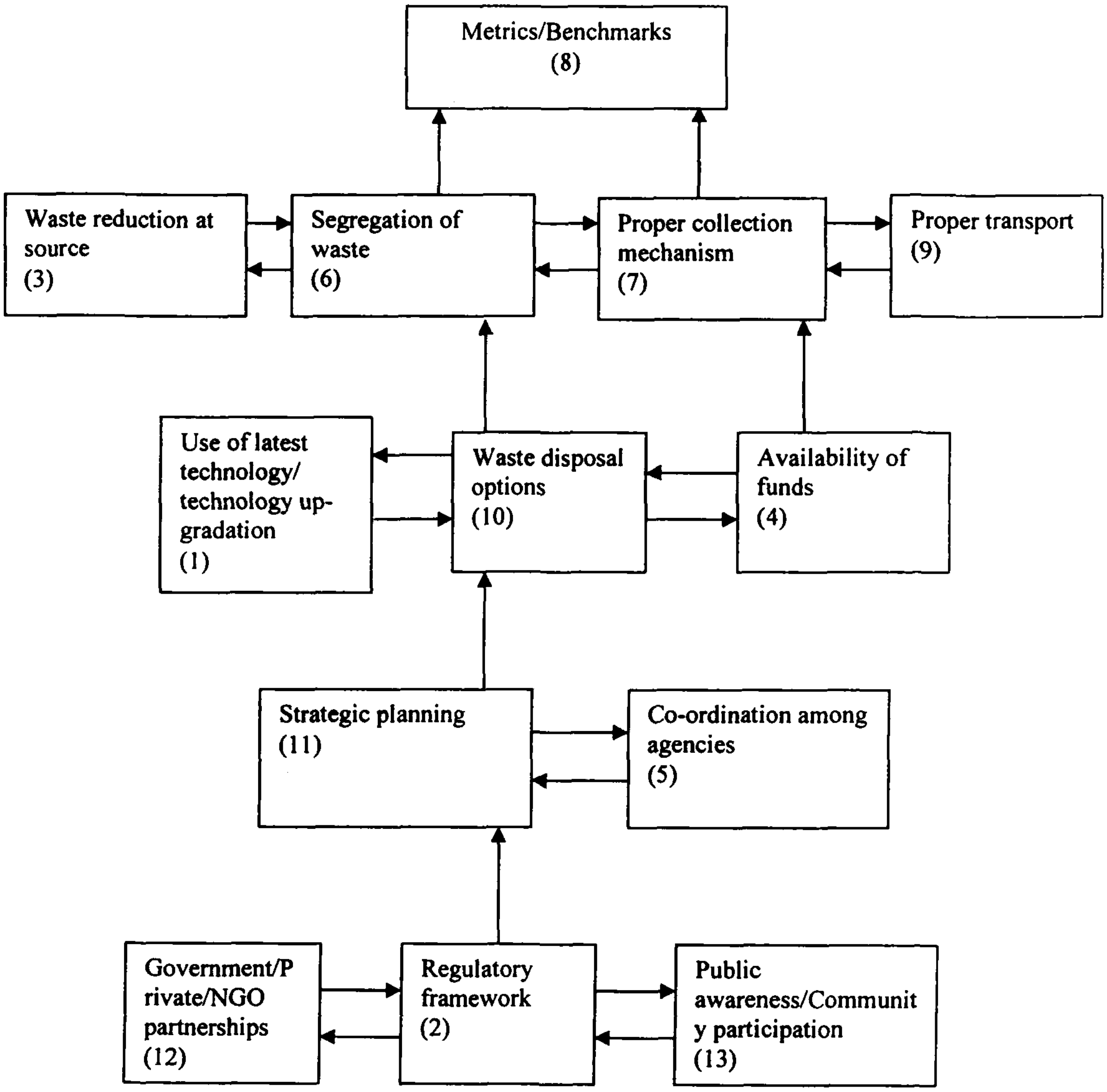


**Figure 6.2: ISM based model for the enablers of MSWM**

The developed model in the Figure 6.2 highlights the important enablers that may assist a MSWM scheme in a given area. The most important enablers from the figure are regulatory framework, community participation/ awareness and government/private/NGO partnerships. These variables are the most important enablers and hence, form the base of the hierarchy of the model. The model developed is overwhelmingly dependent upon these variables. Therefore, concerted efforts should be directed towards increasing awareness among the people and the community, so that there is a high rate of public participation and acceptance for the MSWM plans. The general awareness among the citizens encourages the regulatory framework and vice-versa and so do the private/public partnership and the non-governmental organizations (NGOs) such as environmental organizations.

Lack of adequate and updated regulatory framework hampers the strategic planning in the MSWM schemes, which not only impacts the working and co-ordination among the various agencies involved in the management of the municipal sold wastes, but also impacts the funding and the use of latest technology and adoption of efficient waste disposal options.

Scarcity in funds further impacts the waste reduction, segregation, collection and transport of the municipal waste generated; hence, resulting in ambiguous benchmarks and targets for the agencies to achieve.

### *6.5.6 Matrix of Cross Impact Multiplications Applied to Classification (MICMAC) Analysis*

The objective of the MICMAC analysis is to analyze the driver power and the dependence power of the variables (Mandal and Deshmukh, 1994; Faisal et al., 2007). These variables are classified into four clusters as shown in Figure 6.3. The first cluster consists of the 'autonomous enablers' that have weak driver power and weak dependence. These enablers are relatively disconnected from the system, with which they have only few links, which may be strong. Second cluster includes the 'independent enablers' having strong driving power but weak dependence. Third cluster has the 'linkage enablers' that have strong driving power and also strong dependence. These enablers are unstable in the fact that any action on these barriers will have an effect on others and also a feedback on themselves. Fourth cluster consists of the 'dependent enablers' that have weak driver power but strong dependence. It is observed that a variable with a very strong driving power called the key variable, falls into the category of independent or linkage enablers. The driving power and the dependence of each of the enablers are shown in Table 6.5.3. In this table, an entry of '1' along the columns and rows indicates the dependence and driving power, respectively. Based on the values of Table 6.5.3, the driver power–dependence diagram is constructed which is shown in Figure 6.3. As an illustration, it is observed from Table 6.5.3, enabler 5, for MSWM, has a driving power of 10 and a dependence of 5.

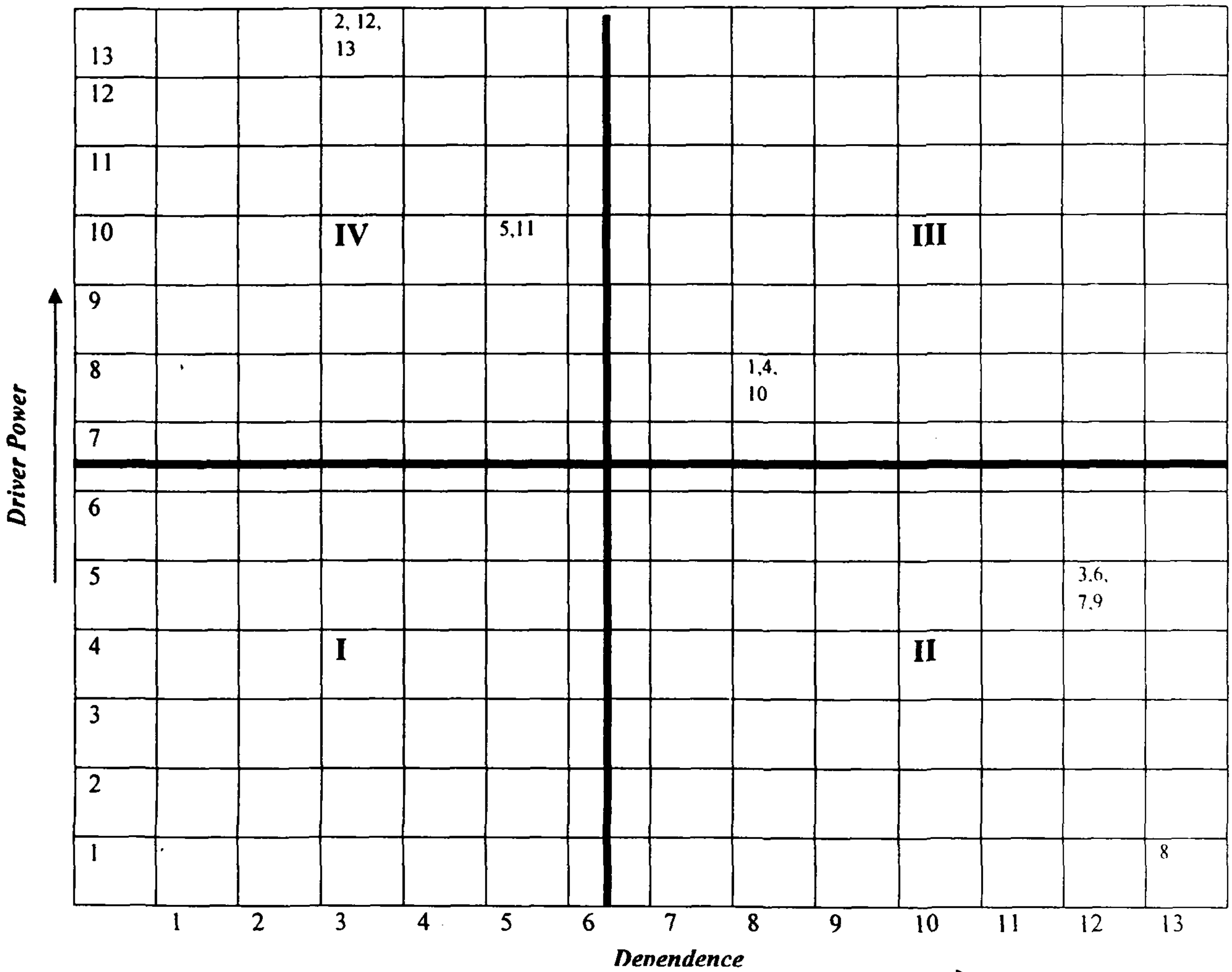


**Figure 6.3: Driver-dependence diagram for the enablers of effective municipal solid waste management**

## 6.6 DISCUSSION ON MODEL FOR ENABLERS TO EFFECTIVE MUNICIPAL SOLID WASTE MANAGMENT

The driver-dependence diagram helps to classify various enablers into groups or clusters. The rationale of this classification is based on the premise that variables having similar driving power-dependence would have comparable impact on the overall system under consideration. For this model developed in this chapter, there are no variables in the autonomous cluster, which indicates that no variable can be considered as disconnected from the whole system and the management has to pay attention to all the identified enablers of municipal solid waste management. Under the category of 'linkage variables' three variables; the use of latest technology, availability of funds and waste disposal options; fall in model developed for MSWM. These variables are of the middle order as they are impacted by the variables such as strategic planning and co-ordinating agencies, and impact the segregation, collection of the MSW generated. The third category is of variables with high dependence like metrics/ benchmark, proper transport, proper collection mechanism, waste segregation and waste reduction at source. These variables have little driving power and high dependence, which implies that to improve these variables organizations, such as the municipalities, has to work upon lower level variables. The last category is of key variables like public awareness/ community participation, regulatory framework and government/private/NGO partnerships in the MSWM model for enablers. These are the key for the planning, implementing and effective working of a MSWM scheme in any area. These variables have the highest driving power and lowest dependence, which indicates that these variables should be considered of utmost importance in order to solve the problem of MSWM.

## 6.7 MODEL FOR THE BARRIERS TO EFFECTIVE HOSPITAL SOLID WASTE MANAGEMENT

### *6.7.1 Barriers to effective Hospital Waste Management (HWM)*

Rapid urbanization in developing economies has resulted in medical facilities in urban centres increasing faster than those in the rural areas. Waste management systems in the urban areas are already overburdened. Hence, an additional load due to mixing of infectious waste aggravates the problem (Patil and Shekdar, 2001). Hospitals and other health-care establishments produce a significant quantity of waste, posing serious problems for its disposal, an issue that has received scant attention (Patil and Pokhrel 2005). After an exhaustive literature review and discussion with experts' thirteen factors have emerged as the most important barriers to effective hospital waste management.

*1. Lack of segregation mechanism:* It has been observed that in many cases the segregation of wastes is undertaken solely at the point of generation, which increases the risks associated with incorrect segregation. Thus, lack of existence of proper segregation mechanism might lead to the hazardous hospital wastes entering a more general domestic waste stream, thereby exposing even those who are involved in domestic waste management to risks (Blenkharn, 2008; Da Silva et al., 2005). Thus, it is imperative that adequate organizational, economic and technical conditions for both efficient segregation and disposal of hospital waste, including pre-treatment systems like efficient steam or microwave disinfection should be adopted (Bencko et al., 2003).

*2. Lack of enforcement mechanism of regulations for HWM:* Today, collection, transportation and disposal of waste are complicated issues and require to be regulated by stringent rules. The issues are so important that in many industrialized countries, specific rules and regulations have been implemented for medical institutions, regardless if they belong to the public or to the private sector (Diaz et al., 2005; Askarian et al., 2004). A study by Gupta and Boojh (2006) in India, demonstrates the need for strict enforcement of legal provisions and a better environmental management system for the disposal of bio-medical waste. At present, the policy makers' and other agencies responsible for the management of hospital waste are in the process of evolving strategies and action plans to implement the regulations.

*3. Lack of awareness of potential risks*: A fundamental issue concerning hospital waste disposal is the assessment of the real and potential risks emanating from waste with the focus on the risk of infection (Muhlich et al., 2003). Increasing awareness about the potential risks from hospital waste requires special efforts, because the hazards and risks exist not just for the waste generators and operators, but also for the general community (Sandhu and Singh, 2003). Lack of awareness about the potential risks from such waste is a major barrier to effective waste management in the health-care sector (Da Silva et al., 2005; Patil and Pokhrel, 2003).

*4. Lack of appropriate guidelines*: Coker et al. (2009) in a study in Nigeria found lack of a formal policy or directives by stakeholders or the government, a major barrier to effective hospital waste management. Inability to follow minimum standards of hospital waste management not only decreases the quality of life and health in a society, but also increases the workload of health services (Askarian et al., 2004; Akhter and Trankler, 2003).

*5. Lack of strategic commitment by the top management*: A major concern of health-care waste management is the non-existence of a comprehensive strategy of managing waste in health-care facilities. This seriously affects the way in which the waste is handled in practice and the compliance with the hygiene and ecological standards (Kaiser et al., 2001). The introduction of a written policy on waste management is crucial in accomplishing waste reduction and cost savings (Almuneef and Memish, 2003). Strategic commitment by top management is necessary for effective policy implementation and to make in-hospital waste management activities an important part of the overall managerial goal of the establishment.

*6. Lack of environmental impact awareness*: Lack of the understanding by the hospital staff and patients about the environmental impact due to improper hospital waste disposal practices is another barrier in effective waste management. In a study by Yong et al. (2009) it was found that in general, people don't understand the difference between medical waste, recyclable waste and ordinary garbage particularly from the point of view of handling these different categories of waste.

*7. Lack of off-site transport facilities*: According to scientific standards, infectious wastes in tropical areas can be kept in a temporary storage area for 24 hours during the hot season and up to 48 hours in cooler seasons (Prüss et al., 1999). It has been found that many of the hospitals don't have transportation facilities for waste and they are dependent on municipal authorities for off-site transportation of waste. These municipal facilities are overburdened and so the waste is not transported within the stipulated time limits, which may result in the transmission of infections.

*8. Untrained staff*: One of the most difficult aspects is changing or modifying the behavioural attitude of the hospital personnel (Almuneef and Memish, 2003). Lack of proper training for different personnel of the hospitals, especially the staff responsible for hospital waste management, regarding the hazards and correct management of hospital waste, results in a major barrier to effective HWM (Askarian et al., 2004; Gupta and Boojh, 2006; Patil and Shekdar, 2001).

*9. Financial constraints*: The issue of effective management of the hospital waste is magnified by a lack of financial resources to support solutions (Birpinar et al., 2009). Lack of proper budget allocation at the provincial and hospital level regarding waste management is a major limitation to effective management of waste (Askarian et al., 2004; Patil and Shekdar, 2001). In a study by Da Silva et al. (2005) in Brazil, economic problems in the country are one of the major barriers for the government from adequately supporting a health-care policy. Gupta and Boojh (2006) also found lack of funds a major barrier in proper hospital waste management.

*10. Lack of metrics to quantify benefits:* Non existence of any metrics that could provide information to waste management staff about the benefits that accrue from proper management of hospital waste is a barrier to effective waste management.

*11. Lack of availability of modern disposal methods*: While incineration is a suitable treatment for most types of medical waste and has several advantages (especially volume reduction of medical waste, destruction of pathogens and hazardous organic matter), it is still an expensive method and may result in the production of many toxic emissions. Thus, the development of alternative treatment technologies for medical waste (e.g. microwave sanitation, chemical disinfection, pyrolysis, and gasification) should be encouraged, replacing unnecessary incineration by potentially more environmentally friendly treatment methods (Jang et al., 2006). Lack of efficient incinerators or low quality of operation and improper treatment of hazardous hospital waste is one of the major issues in hospital waste management (Askarian et al., 2004). This lack of safe thermal destruction of hospital waste could lead to many undesirable side effects (Bencko et al., 2002).

*12. Lack of co-operation and co-ordination among various agencies*: Proper disposal of waste requires co-operation and co-ordination among various agencies involved in the process. These may be firms engaged in transportation, firms involved in final disposal like incineration and land filling and the hospital itself. The lack of co-operation and co-ordination among the various agencies leads to inefficient process of waste disposal (Akhter and Trankler, 2003).

*13. Lack of geographic information system (GIS) based data bank and hospital information systems (HIS)*: The GIS-based maps of the study area are for evaluating the spatial and temporal variations of the solid waste pollution loads. They include pollution loads and solid waste characteristics (Karamouz et al., 2007). Non-availability of such information results in inefficiencies in the waste management process.

### *6.7.2 Structural Self-Interaction Matrix*

For developing an ISM for the barriers to effective hospital solid waste management the procedure described in detail in section 6.5.2 has been adopted. For this model, a contextual relationship of "aggravate" type is chosen to exist among the barriers to effective hospital waste management. This means that one variable tends to aggravate another variable. Based on this, contextual relationship between the variables is developed. Keeping in mind the contextual relationship for each variable, the existence of a relation between any two barriers (*i* and *j*) and the associated direction of the relation is questioned. Four symbols are used to denote the direction of relationship between the barriers (*i* and *j*):

V: Barrier *i* will aggravate Barrier *j*;

A: Barrier *j* will aggravate Barrier *i*;

X: Barrier *i* and *j* will aggravate each other; and

O: Barriers *i* and *j* are unrelated.

The use of the symbols V, A, X, and O in structural self interaction matrix (SSIM) would be elucidated by the following Table 6.7.4

**Table 6.7.4: Structural self interaction matrix (SSIM) for barriers to HWM**

| Barriers | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Lack of segregation mechanism | X | A | V | V | A | A | O | A | A | A | O | A |
| 2. Lack of enforcement mechanism | O | O | V | V | O | V | V | O | O | A | O | |
| 3. Lack of awareness about potential risks | O | O | V | O | V | V | O | X | V | X | | |
| 4. Lack of appropriate guidelines | V | V | V | V | V | V | O | X | V | | | |
| 5. Lack of strategic commitment by top management | O | O | V | O | O | O | O | O | | | | |
| 6. Lack of environmental impact awareness | O | O | V | V | V | V | O | | | | | |
| 7. Lack of off-site transport facilities | A | A | V | O | O | A | | | | | | |
| 8. Untrained staff | O | A | V | A | X | | | | | | | |
| 9. Financial constraints | V | O | O | V | | | | | | | | |
| 10. Lack of metrics to quantify benefits | A | A | A | | | | | | | | | |
| 11. Lack of modern disposal methods | A | A | | | | | | | | | | |
| 12. Lack of cooperation and coordination | O | | | | | | | | | | | |
| 13. Lack of GIS based data bank and MIS | | | | | | | | | | | | |

(i) Barrier 2 (lack of enforcement mechanism) would aggravate barrier 11(lack of modern disposal methods) hence the relationship is V (Table 6.7.4).

(ii) Barrier 1 (lack of segregation mechanism) would be aggravated by barrier 9 (financial constraints). Lack of budget to invest in waste disposal methods would lead to improper segregation and thus the relationship between barrier 1 and barrier 9 is A (Table 6.7.4).

(iii) Barrier 3 (lack of awareness about potential risks) and barrier 4 (lack of appropriate guidelines) aggravate each other so the relationship is X (Table 6.7.4).

(iv) No direct relationship seems to exists between barrier 7 (Lack of off-site transport facilities) and barrier 10 (lack of metrics to quantify benefits) so the relationship is O (Table 6.7.4).

### *6.7.3 Reachability matrix*

The SSIM is transformed into a binary matrix, called the initial reachability matrix by substituting V, A, X, O by 1 and 0 as per the case. The rules for the substitution of 1's and 0's are described in detail in this chapter in section 6.5.3.

Following these rules the final reachability matrix is shown in Table 6.7.5. In Table 6.7.5, the driving power and the dependence of each barrier are also shown. The driving power for each enabler is the total number of barriers (including itself), which it may impact. Dependence is the total number of barriers (including itself), which may be impacting it. These driving power and dependencies will be used in MICMAC analysis, where the barriers will be classified into four groups of autonomous, dependent, linkage, and independent (driver) barriers.

**Table 6.7.5: Final reachability matrix**

| Barriers | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | Driver |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Lack of segregation mechanism | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 5 |
| 2. Lack of enforcement mechanism | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 8 |
| 3. Lack of awareness about potential risks | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| 4. Lack of appropriate guidelines | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| 5. Lack of strategic commitment by top management | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 8 |
| 6. Lack of environmental impact awareness | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| 7. Lack of off-site transport facilities | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 2 |
| 8. Untrained staff | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 7 |
| 9. Financial constraints | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 7 |
| 10. Lack of metrics to quantify benefits | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 11. Lack of modern disposal methods | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 2 |
| 12. Lack of cooperation and coordination | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 8 |
| 13. GIS based data bank and MIS | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 5 |
| Dependence | 10 | 4 | 3 | 3 | 4 | 3 | 11 | 8 | 8 | 13 | 11 | 4 | 10 | |

### *6.7.3 Level partitions*

From the final reachability matrix, the reachability and antecedent set for each barrier are found as described in the sub-section 6.5.4

After the identification of the top-level element, it is separated out from the other elements. Then, the same process as in sub-section 6.5.4 has been repeated to find out the elements in the next level. The following Table 6.7.6 shows the different iterations done. This process is continued, until the level of each element is found. The digraph and the final model are developed from the levels found.

**Table 6.7.6: Iterations for barriers to HWM**

| **Barrier** $p_i$ | **Reachability set** $R(p_i)$ | **Antecedent set** $A(p_i)$ | **Intersection set** $R(p_i) \cap A(p_i)$ | **Level** |
|---|---|---|---|---|
| 1 | 1,7,10,11,13 | 1,2,3,4,5,6,8,9,12,13 | 1,13 | |
| 2 | 1,2,7,8,9,10,11,13 | 2,3,4,6 | 2 | |
| 3 | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 3,4,6 | 3,4,6 | |
| 4 | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 3,4,6 | 3,4,6 | |
| 5 | 1,5,7,8,9,10,11,13,14 | 3,4,5,6 | 5 | |
| 6 | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 3,4,6 | 3,4,6 | |
| 7 | 7,10 | 2,3,4,5,6,7,8,9,12,13 | 7 | |
| 8 | 1,7,8,9,10,11,13 | 2,3,4,5,6,8,9,12 | 8,9, | |
| 9 | 1,7,8,9,10,11,13 | 2,3,4,5,6,8,9,12 | 8,9, | |
| 10 | 10 | 1,2,3,4,5,6,7,8,9,10,11,12,13 | 10 | I |
| 11 | 10,11 | 1,2,3,4,5,6,8,9,11,12,13,14 | 11 | |
| 12 | 1,7,8,9,10,11,12,13, | 3,4,6,12 | 12 | |
| 13 | 1,7,10,11,13 | 1,2,3,4,5,6,8,9,12,13,14 | 1,13 | |
| **Iteration ii** | | | | |
| Barrier $p_i$ | Reachability set $R(p_i)$ | Antecedent set $A(p_i)$ | Intersection set $R(p_i) \cap A(p_i)$ | Level |
| 1 | 1,7,11,13 | 1,2,3,4,5,6,8,9,12,13 | 1,13 | |
| 2 | 1,2,7,8,9,11,13 | 2,3,4,6 | 2 | |
| 3 | 1,2,3,4,5,6,7,8,9,11,12,13 | 3,4,6 | 3,4,6 | |
| 4 | 1,2,3,4,5,6,7,8,9,11,12,13 | 3,4,6 | 3,4,6 | |
| 5 | 1,5,7,8,9,11,13 | 3,4,5,6 | 5 | |
| 6 | 1,2,3,4,5,6,7,8,9,11,12,13 | 3,4,6 | 3,4,6 | |
| 7 | 7 | 2,3,4,5,6,7,8,9,12,13 | 7 | II |
| 8 | 1,7,8,9,11,13 | 2,3,4,5,6,8,9,12 | 8,9 | |
| 9 | 1,7,8,9,11,13 | 2,3,4,5,6,8,9,12 | 8,9 | |
| 11 | 11 | 1,2,3,4,5,6,8,9,11,12,13 | 11 | II |
| 12 | 1,7,8,9,11,12,13 | 3,4,6,12 | 12 | |
| 13 | 1,7,11,13 | 1,2,3,4,5,6,8,9,12,13 | 1,13 | |
| **Iteration iii** | | | | |
| **Barrier** $p_i$ | **Reachability set** $R(p_i)$ | **Antecedent set** $A(p_i)$ | **Intersection set** $R(p_i) \cap A(p_i)$ | **Level** |
| 1 | 1,13 | 1,2,3,4,5,6,8,9,12,13 | 1,13 | III |
| 2 | 1,2,8,9,13 | 2,3,4,6 | 2 | |
| 3 | 1,2,3,4,5,6,8,9,12,13 | 3,4,6 | 3,4,6 | |
| 4 | 1,2,3,4,5,6,8,9,12,13 | 3,4,6 | 3,4,6 | |
| 5 | 1,5,8,9,13,14 | 3,4,5,6 | 5 | |
| 6 | 1,2,3,4,5,6,8,9,12,13 | 3,4,6 | 3,4,6 | |
| 8 | 1,8,9,13 | 2,3,4,5,6,8,9,12 | 8,9 | |
| 9 | 1,8,9,13 | 2,3,4,5,6,8,9,12 | 8,9 | |
| 12 | 1,8,9,12,13 | 3,4,6,12 | 12 | |

| Barrier $p_i$ | Reachability set $R(p_i)$ | Antecedent set $A(p_i)$ | Intersection set $R(p_i) \cap A(p_i)$ | Level |
|---|---|---|---|---|
| 13 | 1,13 | 1,2,3,4,5,6,8,9,12,13 | 1,13 | III |
| **Iteration iv** | | | | |
| **Barrier** $p_i$ | **Reachability set** $R(p_i)$ | **Antecedent set** $A(p_i)$ | **Intersection set** $R(p_i) \cap A(p_i)$ | **Level** |
| 2 | 2,8,9 | 2,3,4,6 | 2 | |
| 3 | 2,3,4,5,6,8,9,12 | 3,4,6 | 3,4,6 | |
| 4 | 2,3,4,5,6,8,9,12 | 3,4,6 | 3,4,6 | |
| 5 | 5,8,9 | 3,4,5,6 | 5 | |
| 6 | 2,3,4,5,6,8,9,12 | 3,4,6 | 3,4,6 | |
| 8 | 8,9 | 2,3,4,5,6,8,9,12 | 8,9 | IV |
| 9 | 8,9 | 2,3,4,5,6,8,9,12 | 8,9 | IV |
| 12 | 8,9,12 | 3,4,6,12 | 12 | |
| **Iteration v** | | | | |
| **Barrier** $p_i$ | **Reachability set** $R(p_i)$ | **Antecedent set** $A(p_i)$ | **Intersection set** $R(p_i) \cap A(p_i)$ | **Level** |
| 2 | 2 | 2,3,4,6 | 2 | V |
| 3 | 2,3,4,5,6,12 | 3,4,6 | 3,4,6 | |
| 4 | 2,3,4,5,6,12 | 3,4,6 | 3,4,6 | |
| 5 | 5 | 3,4,5,6 | 5 | V |
| 6 | 2,3,4,5,6,12 | 3,4,6 | 3,4,6 | |
| 12 | 12 | 3,4,6,12 | 12 | V |
| **Iteration vi** | | | | |
| **Barrier** $p_i$ | **Reachability set** $R(p_i)$ | **Antecedent set** $A(p_i)$ | **Intersection set** $R(p_i) \cap A(p_i)$ | **Level** |
| 3 | 3,4,6 | 3,4,6 | 3,4,6 | VI |
| 4 | 3,4,6 | 3,4,6 | 3,4,6 | VI |
| 6 | 3,4,6, | 3,4,6 | 3,4,6 | VI |

### *6.7.4 Building the ISM-based model*

From the final reachability matrix depicted in Table 6.7.6, the structural model is generated by means of vertices or nodes and lines of edges. If there is a relationship between the barriers *j* and *i* this is shown by an arrow which points from *i* to *j*. This graph is called a directed graph or digraph. The digraph is finally converted into ISM model as shown in Figure 6.3.

From the model, depicted in Figure 6.4, it is clear that the most important barriers that impede effective hospital waste management are lack of appropriate guidelines, lack of awareness about potential risks, and lack of environmental impact awareness. The reason that these variables form the base of the hierarchy based-model is their high driving power. Also, these variables have the least dependence, implying that all the other variables are dependent on them and thus overall effectiveness of hospital waste management system is largely dependent on strategies to effectively manage them.

Because of lack of appropriate guidelines and lack of awareness about potential risks there is no strategic commitment by top management which results in financial constraints as no specific funds are allocated for waste management projects. This lack of strategic commitment also impacts the training aspects of waste personnel. Also, the financial constraints (barrier 9) augment the lack of GIS based data bank and HIS (barrier 13).

Lack of co-operation and co-ordination among various agencies involved in waste management, lack of enforcement mechanism, untrained staff, would lead to lack of modern disposal methods (barrier 11). Financial constraints would impact the lack of off-site transport facilities (barrier 11). Also, lack of metric to quantify benefits would affect the waste management activities as the agencies involved in the process are not aware of what exactly they are achieving from proper management of waste in hospitals.

### *6.7.5 Matrix of Cross Impact Multiplications Applied to Classification (MICMAC) Analysis*

As discussed earlier, the objective of the MICMAC analysis is to analyze the driver power and the dependence power of the variables (Mandal and Deshmukh, 1994; Faisal et al., 2007). These variables are classified into four clusters as shown in Figure 6.5.

I. The 'autonomous barriers': weak driver power and weak dependence.

II. The 'independent barriers': having strong driving power but weak dependence.

III. The 'linkage barriers': strong driving power and also strong dependence.

IV. The 'dependent barriers': that have weak driver power but strong dependence.

The driving power and the dependence of each of the barriers are shown in Table 6.7.6. In this table, an entry of '1' along the columns and rows indicates the dependence and driving power, respectively. Based on the values of Table 6.5.3, the driver power–dependence diagram is constructed which is shown in Figure 6.5. As an illustration, it is observed from Table 6.7.6 that the barrier 5, for effective HWM, is having a driver power of 8 and a dependence of 4. Therefore, in this figure, it is positioned at a place corresponding to a driver power of 8 and a dependence of 4.

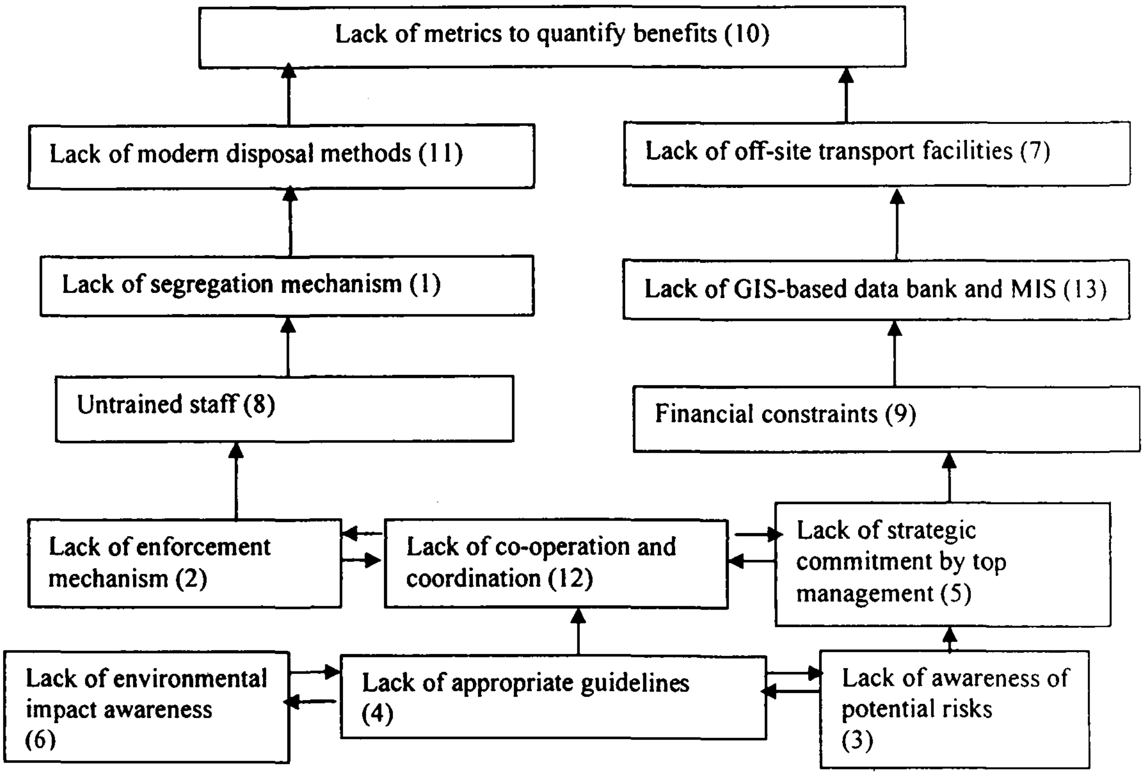


**Figure 6.4: ISM based model for the barriers of hospital waste management**

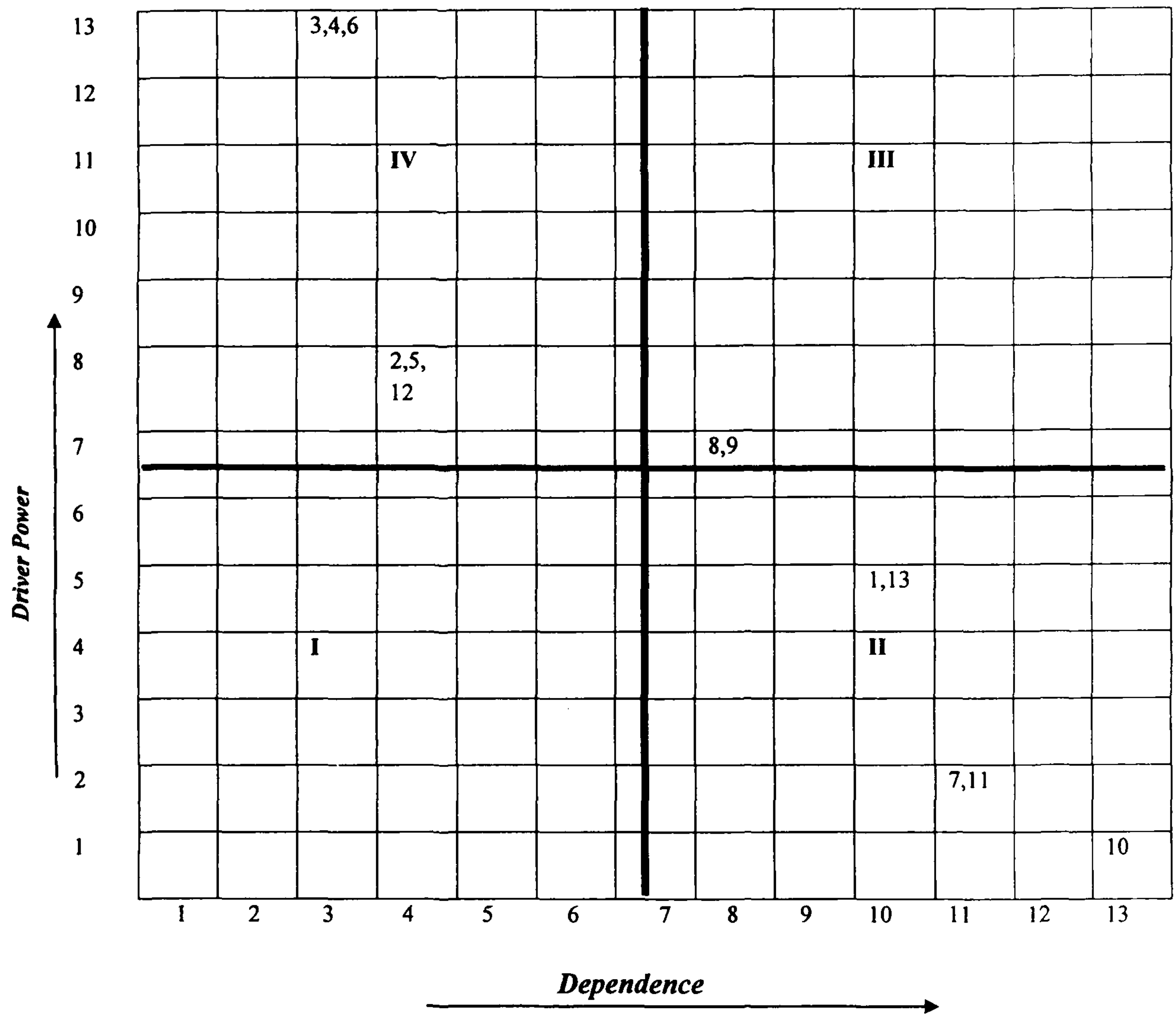


**Figure 6.5: Driver-dependence diagram for the barriers of effective hospital waste management**

## 6.8 DISCUSSION ON MODEL FOR BARRIERS TO EFFECTIVE HOSPITAL WASTE MANAGMENT

The driver-dependence diagram helps to classify various barriers into groups or clusters. The rationale of this classification is based on the premise that variables having similar driving power-dependence would have comparable impact on the overall system under consideration. For the models developed in this chapter, there are no variables in the autonomous cluster, which indicates that no variable can be considered as disconnected from the whole system and the management has to pay attention to all the identified barriers of hospital waste management. Under the category of 'linkage variables' , which are the variables of the middle order, two variables 'untrained staff' and 'lack of financial resources' have emerged in the model developed for the barriers to effective hospital waste management. These barriers are impacted by the lower level barriers and in turn they impact the upper level barriers. Without proper training, the staff cannot handle the waste effectively, so as to minimize the potential health and environmental risks. Training requires investments, which are dependent on strategic commitment by top management and environmental impact awareness among the citizens. The third category of variables with high dependence under the hospital waste model are 'lack of metrics to quantify benefits', 'lack of modern disposal methods' and 'lack of off-site transport facilities', 'lack of segregation mechanism', and 'lack of GIS-based data bank and MIS'. These variables have little driving power and high dependence, which implies that to improve these variables organizations have to work upon lower level variables. The key variables, which are he last category of variables, 'lack of environmental impact awareness', 'lack of appropriate guidelines', and 'lack of awareness of potential risks' surfaced as the key barriers. These variables have the highest driving power and lowest dependence, which indicates that these variables should be treated as the root cause of the problem.

## 6.9 CONCLUSIONS

The iterative process of ISM modelling approach used in this research provides an understanding of how the various enablers and barriers to effective municipal sold waste management and hospital waste management, respectively, interact with each other. This is important as generally, the focus is on one or two variables, which are thought to be significant without taking into consideration those that may be the real enablers/barriers to effective waste management. For example, authorities might try to focus more on the adoption of modern disposal methods without proper consideration of co-ordination and co-operation among various agencies involved in both kinds of solid waste management. This would make the adoption of new methods ineffective with costs to the society. To understand, which of the variable is more critical, the model developed delineates the variables which are supposed to be the most important enablers or barriers to effective waste management. There is an urgent need to understand and develop suitable strategies to counter these variables as they in turn impact other variables at higher levels of the hierarchy. ISM model would help the waste management strategists to understand the relationships among the variables to effective solid waste management.

In a developing economy like India a large population exits, which is still not conscious about the environmental impacts of solid waste disposal. This, also, includes many of those, who are in the policy making level of the government. This leads to lack of clear guidelines and improper enforcement mechanism. Lack of effective management plan or guidelines not only put environmental and public health at risk, but give enough leverage to violators to pollute with impunity. This eventually leads to overall degradation in the standard of living of a community. Public awareness, political will and public participation are essential for the successful implementation of the legal provisions and to have an integrated approach towards sustainable management of municipal solid wastes in the country (Joseph, 2002). New and emerging techniques that may be cost-effective and efficacious in handling of the municipal solid waste and hospital wastes are not explored or utilized due to the scepticism developed for the past failures of the guidelines. This further puts financial burden on the civic bodies, which are required to work in tandem with the medical facilities to dispose the hospital waste and to dispose the municipal waste as well. Thus, there is an urgent need to study exhaustively the variables that encourage effective MSWM, so that the world-wide menace of augmenting MSW could be tackled in order to diminish the environmental and health hazards. Moreover, understanding the various relationships among the variables, which aid sound MSWM, is essential so that the decision-makers in a SWM plan can take appropriate steps in formulating a plan and can arrive upon a more technically justifiable an environmentally sustainable plan.

It is very important to segregate the waste before treatment and disposal because this helps to identify hazardous and potentially infectious waste and thereby reduces overall handling cost. Efficacious segregation could be achieved at the point of waste generation through proper training, cleanliness standards and tough enforcement. Training on handling and management of sharps is essential. Health-care establishments should be encouraged to practice environmental management system, which is a set of processes and practices that enable an organization to reduce its environmental impacts and increase its operating efficiency. However, the need to be profitable and competitive in the health-sector makes the top management think little for their environmental responsibilities. There is more focus on other goals by top management in the hospitals, which further leads to lack of allocation of funds for proper acquisition and adoption of modern disposal methods for hospital waste.

It should be a goal of any health-care establishment to work towards ISO 14001certification, in order to provide not only the best health-care to the clients, but also to provide a better environment to all the people in the vicinity. ISO 14001 is International Organization for Standardization's framework for a holistic, strategic approach to the organization's environmental policy, plans and actions. Environmental management systems should be strongly promoted in all hospitals through awareness programs, training and demonstration projects. Introducing awareness programs, education and training initiatives should cover all stakeholders concerned with medical waste management. Media should be used effectively to create awareness and disseminate the knowledge, among the general public, about the health and environmental impacts of the improper handling and disposal of any kind of solid waste. It is essential in order to encourage a self-regulation for waste reduction, segregation and adopting environmental conscious practices by the citizens.

## 6.10 LIMITATIONS AND SCOPE FOR FUTURE RESEARCH

In this chapter thirteen variables are identified for modeling the barriers to effective hospital waste management from the perspective of healthcare system in India. As the basis of identification of variables is literature review, there is a possibility that some issue might have been gone unnoticed by the researchers. Further, in this paper the researchers have combined certain variables like lack of GIS and HIS. In some cases there might be an HIS existing in the hospital with no GIS. Thus, to improve the generalizability of the framework developed in this research, future research can be carried out in other settings which may have some difference of variables affecting effective hospital waste management to develop ISM. In developing the model, some experts' both from academia and field were contacted to help in the analysis of driving and dependence power of the variables. Hence, the framework developed might have some element of bias. Through ISM a relationship model among the variables of effective hospital waste management has been developed, but model has not been statistically validated. Path analysis or structural equation modelling (SEM) approach has the capability of testing the validity of such hypothetical model. AMOS or LISREL software's can be used to examine the relationships derived from this model. Therefore, in the future research it may be applied to test the validity of this model.

# CHAPTER 7

# SUMMARY, LIMITATIONS AND SCOPE FOR FUTURE WORK

## 7.1 INTRODUCTION

The burgeoning population and the ever increasing throw-away culture shored up by the increasing innovations, research and development necessitates greater expertise, understanding the nitty-gritty of the SWM schemes. As discussed before, SWM is an amalgamation of a number of issues such as technical, political, social, economic etc; its management becomes a tedious and skewed task if techniques such as MCDM are not available.

Holistic management of SWM, taking into account of the various conflicting criteria, is a developing discipline and studies in this area are scarce. This has been a big motivator to the researcher to explore various issues related to management of MSWM and HWM. One of the primary objectives of this research was to examine the issues related to management of MSW in Class I Indian cities through a questionnaire-based survey and contrasting it with some other developing country's city to understand the trend of solid waste generation and behavior of the people towards participation in these MSWM schemes.

One of the major difficulties encountered by the managers in developing an effective solid waste management plan is the lack of any instrument which can be applied for prioritization of the various variables. Fuzzy analytic hierarchy approach (Fuzzy-AHP) can appropriately prioritize various variables for management of solid wastes and helps engineers, municipal managers and decision-makers to understand, which factors are more important from implementation and design of the MSWM scheme with the point of view of the various requisites and the stake-holders involved. The fuzzy-AHP methodology has also been applied to enlist the prioritization of the factors that may determine the best possible infectious waste disposal firm.

As there are many disposal alternatives for MSW, there is a need of a tool to select the best set of alternative to dispose off the MSW in an innocuous way and in tandem with the environmental laws as well. Also this framework must be comprehensive enough to include all the possible interactions in the MSWM. Analytic network process (ANP) is the appropriate tool to select the best possible alternative, since it takes into account the various feedbacks among the factors apart from their interactions. ANP is also handy, when selecting the best infectious waste contractor as it integrates all the requisites and barriers for a good infectious waste firm.

The literature review and questionnaire survey suggest that there are a number of variables, which act as enablers/barriers of MSW and HWM. Analysis of the interrelationships among these variables is possible using interpretive structural modeling (ISM). The models developed could be a vital source of information to the managers regarding those variables, which should be targeted upon in order to develop an efficacious solid waste management plan.

### 7.2 SUMMARY OF RESEARCH

This research has attempted to fill some of the gaps in the contemporary research on solid waste management. In this section, the work done towards achieving the research objectives is presented. In the next section, the major findings of this research are enlisted.

The main works undertaken in this research include the following:

- An extensive literature review has been conducted to identify the gaps and relevant research issues in the SWM.
- Based on literature review and discussions with academicians, municipal engineers, and infectious waste managers a set of research hypotheses were formed. These hypotheses are related to management of solid wastes both municipal and hospital.
- A questionnaire was designed to elicit responses from the people. Responses from 205 individuals were used in the survey. The responses to the questionnaire helped us to understand the status of management of solid waste and related

issues in MSWM in Indian cities. A similar study was conducted in the capital city of Qatar, Doha to understand the psyche of the people in another Asian city and contrast it with the findings in the Indian setting. Another study was carried out to understand the major problem areas in the management of the infectious waste management in the hospitals.

- The statistical analysis of the questionnaire and hypothesis testing was done
- Thirteen important enablers and barriers that impact MSWM and HWM were identified from the review of the literature and in consultation with experts, both from municipality, hospitals and academia.
- ISM based models were developed to understand the mutual relationships among the various enablers and barriers of MSWM and HWM.
- Fuzzy analytic hierarchy approach (fuzzy-AHP) was applied to map and prioritize important factors in MSW and infectious waste handling.
- An analytic hierarchy approach (ANP) based framework was developed to select the best set of techniques to dispose the MSW and to select the best available infectious waste disposal firm.

## 7.3 KEY FINDINGS FROM THE RESEARCH

Application of MCDM to solve the problems related to SWM is an emerging field of study. There is growing importance of understanding SWM in entirety is receiving attention from both the academicians and the decision makers in SWM due to its complex nature and far-reaching impacts.

Some of the key findings from this research are as follows:

- The focus in SWM studies is on the various emerging and new technologies being used to dispose the solid waste, but there exists a gap in studying the psyche of the people, who are involved and hold the key to any success for the management of such schemes.

- Participation of people increases due to environmental concern and the easily accessible infrastructure of such as curbside recycling.
- Women seemed to take a lead in the programs aimed for management of solid wastes in any given area.
- In the study it was found out that there exists a significant difference among the people of different age groups regarding their involvement in the SWM plans.
- Though feedback about the state of the management of the solid waste has emerged as a major element of any SWM scheme being implemented, the executioners and the formulators remain non-committal about disseminating the results of the scheme.
- The percentage of population involved in recycling and composting plays a more important role in the formulation of scheme for MSWM than the population served through the implemented scheme.
- Incineration as a disposal method for the MSW was rejected primarily due to utilizing incineration warrants installing expensive environmental control systems. Moreover, the composition of the municipal waste generated in the Indian cities is not suitable for the combustion purposes.
- Segregation of the MSW is the key to effective and efficient MSWM. Therefore, public participation is must to combat the problem of municipal solid waste.
- Several constraints such as cost, waste characteristics and the social practices and inhibitions exists that makes difficult for the civic agencies to adopt the state-of-the- art technologies for SWM that are being used in the developed countries all over the world.
- A combination of techniques (such as landfilling and composting) is the best approach for the disposal of MSW in India. Incineration is the least preferred disposal option for MSW not only because of the heavy investment involved in the installation of air pollution control devices, but because the characteristics and composition of the municipal waste are unsuitable for incineration.
- Redress and appeal system and conforming environmental regulations are the two most important criteria in selection of the infectious waste contractors.

- From the study it was found that, when selecting the infectious waste contractor hospitals gave more weightage to the contractor's qualification followed by contractor's service capability. This entails that the health-care organizations are quite concerned about the environmental regulations and are determined to innocuously dispose the infectious waste generated.
- Ambiguous policies exist in the bio-medical or infectious waste management; lack of appropriate guidelines and lack of awareness about potential risks there is no strategic commitment by top management leading to financial constraints impacting the training of personnel involved in handling of the infectious waste.
- Lack of co-operation and co-ordination among various agencies involved in the infectious or the bio-medical waste management exists, which results lack of enforcement mechanism, modern disposal methods and off-site transport facilities.

## 7.4 IMPLICATIONS OF THE RESEARCH

The findings of this research contribute to the body of SWM literature. From a practical perspective, the analysis reveals that decision-makers such as mangers, engineers and consultants etc have to look beyond their boundaries and there is an urgent need to study the various streams of SWM in a holistic way to curb the growing menace created by the generation of solid wastes.

The results of the questionnaire survey, fuzzy-AHP model, ANP model and ISM model, provide new insights on the management solid wastes and demonstrate that there is need to consider all the aspects and issues of the solid waste; for the efficacious management and sturdy plan, which addresses all the concerns of the stake-holders and the legislation as well. The study of the various kinds of solid wastes management with issues in isolation fails to design a robust and effective plan and the outcomes therefore, have limited success.

### *7.4.1 Implications to academicians*

- The literature review presented in this research and identified gaps in the literature may provide a basis for the future research.
- The questionnaire developed in this research could be used as an instrument for conducting further empirical studies in management of solid waste.
- In this research, fuzzy analytic hierarchy approach (fuzzy-AHP) has been used to prioritize factors like environmental, social and economic. This approach provides an easy method to prioritize other issues of SWM.
- In this research, analytic network process (ANP) based framework has been used to select the best approach to dispose MSW and select the best infectious waste disposal firm. This multi-criteria decision making tool may motivate academicians to apply this model to other decision making issues related to management other kinds of solid wastes.
- In this thesis, a study of the issues related to management of MSW and infectious waste has been explored in context of Indian scenario. Thus, it may serve as a valuable input for future research in this area.
- The ISM framework for modeling the enablers/barriers for effective municipal and infectious waste management respectively can be extended to model other issues and other kinds of solid wastes.

### *7.4.2 Implications to practitioners*

Several important managerial implications emerge from this research.

- Perceptions of decision-makers such as manager and engineers and stake-holders related to various issues related to SWM in areas of municipal and infectious wastes have been elicited.
- Feedback about the success or failure, of the target, the implemented SWM scheme is an essential part for the motivation for the people and organizations

such as hospitals to remain involved in the SWM practices. Information sharing, collaborative relationships and trust among the different stake-holders in the plan for management of any kind solid waste has emerged as the major enablers for the failure-risk mitigation in SWM schemes. Thus, the managers, engineers in control of the implementing the scheme in organizations such as hospitals and in different areas need to reorient and modify the plan by incorporating feedback as an essential feature.

- It is observed from the survey that joint working with academicians is a preferred strategy to manage solid wastes, but in actual practice this is not applied by the managers. It is mainly due to the fact that of red-tape prevailing in the government bodies and the urgent need of taking some action on the ground makes it difficult to do so.

- In this research, MSW and hospital waste (infectious) were analyzed. The analysis involved the assessment of the management of these solid wastes, is primarily, in accordance with the legislation and demands of the public. The tool can be replicated for other solid wastes such as industrial and hazardous wastes to provide an easy to understand format and intricacies of the various kinds of solid waste management in depth.

- The ANP framework is comprehensive in the sense that it considers all the possible interactions in a SWM. This framework encompasses many important criteria in the management solid wastes and therefore it may serve as a good aid to the managers, consultants and engineers in selecting the best alternatives for various issues in management of solid wastes.

- The prioritization of solid waste management factors using fuzzy-AHP provides a simple methodology to the practitioners to analyze their solid waste schemes and make them more effective and robust. The single numerical indices developed in this research may serve as a guide in comparing and benchmarking solid waste management schemes.

- Dissemination of information and environmental awareness are the keys to the effective waste management of any type. Decision–makers should adopt various communication strategies that are critical to share information and understand the concerns of the various stake-holders for the adequate performance of any SWM schemes.

- Health-care facilities should be encouraged to work towards achieving ISO 14001certification. ISO 14001 is International Organization for Standardization's framework for a holistic, strategic approach to the organization's environmental policy, plans and actions.

- Environmental management systems should be strongly promoted in all health-care establishments through awareness programs, training and demonstration projects.

## 7.5 LIMITATIONS OF THIS RESEARCH AND SCOPE FOR FUTURE WORK

This research has some limitations too. In this section the limitations of this research and some suggestions for future work are presented.

As applicable to other empirical studies in the area of solid waste management, this research covers only select issues as related to the denizens of the Class I cities which represent a small segment of the vast population of India. The responses to the questionnaire reflect only the perception of the individuals who have filled the questionnaire and cannot be generalized. Since he study primarily covers the Class I cities, this could limit the findings as these cities work under similar type of political, economic, and social environment.

Another major limitation of the study is the limited understanding of the psyche of the people impacted by a scheme of SWM. The concept is yet to take roots in India, though some work has been undertaken at a very small scale. The framework for the assessment of psychology towards the solid wastes per se may differ from geographical region, economic strata etc. There is an urgent need to carry out such more studies to arrive at better options for the management of solid wastes. Since the study conducted has been done in metropolitan area, it is may be subjective and the attitudes of the people are from the same geographical region of the country, thereby limiting the generalization of the results.

In this research, prioritization of the factors related to MSW and infectious waste contractors has been carried out, but some of these frameworks are not evaluated for actual practical settings. So it is suggested that these models may be further verified in real-life settings with the help of the experts. Also, for the sake of simplicity all the subsystems and sub-subsystems associated with all the variables haven't been considered. In future work, various subsystems and sub-subsystems can be delineated and then their impact be taken into account to develop a more comprehensive model. Further, comparative data can be generated to benchmark various kinds of solid waste management schemes from different geographical areas to understand the various factors and interactions among the enablers/ barriers in a SWM plan in the different settings; and to understand and predict the potential success of a waste management plan with the community participation.

Fuzzy-AHP has been used to develop a priority scale of the factors that may ameliorate certain approaches to the SWM on part of the decision-makers. Since, the method used has been with an assumption of independency the priority developed may change, while making selections and executing the scheme in actual scenario. Moreover, there may certain biases and human errors exist, so it is required to capture and understand all the interdependencies etc among the factors through additional model refinement.

The ANP framework has been used to find out the best alternative to dispose the MSW and select the best available infectious waste contractor, the future research could target upon carrying out sensitivity analysis of the model. Also, this framework was tested for a medium sized hospital and Class I city so future work can take data from other size of the hospitals and cities.

In the present research ISM based models for the enablers/barriers of MSW and infectious waste management have been developed. Experts' help have been sought to develop the contextual relationships for the ISM models, which may have introduced some element of bias. Also, this model is not statistically validated. In future extension of this work it is proposed to apply structural equation modeling (SEM) technique, commonly known as linear structural relationship approach to statistically corroborate the findings from ISM model.

## 7.6 CONCLUSIONS

Use of MCDM models in SWM is an issue which is gaining importance in the realms of SWM research. SWM is a very complex issue per se with many political, financial, environmental, technical and information aspects influencing the actual scenario on the ground. In order to ensure that efficient management of any kind of solid waste is carried out all these plethora of concerns and issues need to be addressed and accounted for. Thus, there is a growing realization among the practitioners that any issue or concern, if not dealt with satisfactorily, of SWM scheme can have a direct effect on its success and effectiveness in the area of its implementation. Thus, there is an urgent need to understand issues/factors in solid waste management perspective and develop a set of coherent strategies to manage them.

# REFERENCES


1. Abdulla, F., Qdais, H. A. and Rabi, A. (2008) 'Site investigation on medical waste management practices in northern Jordan', *Waste Management*, Vol. 28, pp. 450-458.
2. Adsavakulchai, S. (2002) 'Study on waste from hospital and clinics in Phitsanulok', *Online Journal of Health and Allied Sciences*, Vol. 3, pp. 3–11.
3. Agarwal A., Shankar R., and Tiwari M.K. (2006) 'Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach', *European Journal of Operational Research* Vol.173, pp. 211-225
4. Ağdağ, O.N., and Sponza, D.T. (2007) 'Co-digestion of mixed industrial sludge with municipal solid wastes in anaerobic simulated landfilling bioreactors', *Journal of Hazardous Materials* Vol. 140, pp. 75–85.
5. Ahmed, K. and Jamwal, N. (2000) 'A heap of a problem', *Down to Earth*, New Delhi, Center for Science and Environment
6. Ahring, B. K. (2003) 'Biomethanation II' In: Scheper, T. (Ed.), *Advances in Biochemical Engineering/Biotechnology*, vol. 82. Springer, Berlin, pp. 220
7. Akter, N and Trankler, J. (2003) 'An analysis of possible scenarios of medical waste management in Bangladesh', *Management of Environmental Quality: An International Journal*, Vol. 14, No. 2, pp. 242-255
8. Alagöz, A. Z. and Kocasoy, G. (2008) 'Improvement and modification of the routing system for the health-care waste collection and transportation in Istanbul', *Waste Management* Vol. 28, No. 8, pp. 1461-1471.
9. Alhumoud, J. M. (2005) 'Municipal solid waste recycling in the Gulf Co-operation Council states', *Resources, Conservation and Recycling*, Vol. 45, pp. 142–158
10. Alhumoud, J. M. and. Alhumoud, H. M. (2007) 'An analysis of trends related to hospital solid wastes management in Kuwait', *Management of Environmental Quality: An International Journal*, Vol. 18, No. 5, pp. 502-513
11. Alidi, A. (1996) 'A multiobjective optimization model for the waste management of the petrochemical industry', *Applied Mathematical Modelling* , Vol. 20, pp. 925–933
12. Almuneef, M. and Memish, Z. (2003) 'Effective medical waste management: it can be done', *American Journal of Infection Control*, Vol. 31, No. 3, pp. 188-192
13. Alvim Ferraz, M.C.M., Barcelos Cardoso, J.I. and Ribeiro Pontes, S.L. (2000) 'Concentration of atmospheric pollutants in the gaseous emissions of medical waste incinerators', *Journal of Air and Waste Management Association*, Vol. 50, pp. 131–136.
14. Alvim-Ferraz, M. C. M. and Afonso, S. A. V. (2003) 'Incineration of different types of medical wastes: emission factors for gaseous emissions', *Atmospheric Environment*, Vol. 37, No. 38, pp. 5415-5422
15. Al-Wattar , O. M. (2006) 'Population, residential solid waste generation and containers needed in mosul city', *The Journal of Solid Waste Technology and Management* Vol. 32, No.2, pp. 89-108
16. Ananth, A. P., Prashanthini, V. and Visvanathan, C. (2010) 'Healthcare waste management in Asia', *Waste Management*, Vol. 30, pp. 154-161
17. Anonymous, (2002) 'Managing Infection Control', 2002
18. Aragonés-Beltrán, P., Pastor-Ferrando, J. P., García-García, F., and Pascual-Agulló, A. (2010) 'An analytic network process approach for siting a municipal solid waste plant

in the metropolitan area of Valencia (Spain)', *Journal of Environmental Management* Vol. 91, pp. 1071–1086

19. Arey M. J., Baetz, B.W., Macdonald, P.D.M. and Byer, P.H. (1993)' Use of mixed probability distributions for the analysis of solid waste generation data', Waste Management and Res earch, Vol.11, pp. 387–402
20. Askarian, M., Vakili, M. and Kabir, G. (2004) 'Results of a hospital waste survey in private hospitals in Fars province, Iran', *Waste Management* Vol. 24, pp. 347–352.
21. Aye, L. and Widjaya, E.R. (2006) 'Environmental and economic analyses of waste disposal options for traditional markets in Indonesia', *Waste Management* Vol. 26, No.10, pp. 1180–1191
22. Baetz, B. W., Pas, E. I. and Vesilind P. A. (1991) 'Waste-reduction primer for managers', *Journal of Management in Engineering*, Vol. 7, No. 1, pp. 33-42
23. Bana e Costa, C.A., Stewart, T.J. and Vansnick, J.C., (1997) 'Multicriteria decision analysis: Some thoughts based on the tutorial and discussion sessions of the ESIGMA meetings', *European Journal of Operational Research* Vol. 99, pp. 28–37
24. Barlishen, K. D. and Baetz, B. W. (1996) 'Development of a decision support system for municipal solid waste management systems planning', *Waste Management & Research,* Vol. 14, pp. 71–86
25. Barr, S., Gilg, A.W. and Ford, N.J. (2001) 'A conceptual framework for understanding and analyzing attitudes towards household-waste management', *Environment and Planning A* Vol. 33, No.11, pp. 2025-2048
26. Barton, J.R., Dalley, D. and Patel, V.S. (1996) ' Life cycle assessment for Waste Management', *Waste Management* Vol. 16, No.1–3, pp. 35–50
27. Bastian, R. (1997) 'The biosolids (sludge) treatment, beneficial use, and disposal situation in the USA', *European Water Pollution Control Journal* Vol. 7, No. 2, pp. 62-79. March.
28. Baveja, G., Muralidhar, S. and Aggarwal, P. (2000) 'Hospital waste management-an overview', *Hospital Today*, Vol. 5, pp. 485-486
29. B-Chang, N., H-Chang, Y. and W- Chen, H. (2009) 'Fair fund distribution for a municipal incinerator using GIS-based fuzzy analytic hierarchy process', *Journal of Environmental Management* Vol. 90, pp. 441-454
30. Bdour, A., Altrabsheh , B., Hadadin , N. and Al-Shareif , M. (2007) 'Assessment of medical wastes management practice: A case studyof the northern part of Jordan, *Waste Management* Vol. 27, pp. 746-759
31. Becker, C.E., Cone, J.E. and Gerberding, J. (1989) 'Occupational infection with human immunodeficiency virus (HIV). Risks and risk reduction', Annals of Internal Medicine Vol. 110, No. 8, pp. 653–656
32. Beigl, P., Lebersorger, S., and Salhofer, S. (2008) 'Modelling municipal solid waste generation: a review', *Waste Management*, Vol. 28, pp. 200–214
33. Bencko, V., Kapek, J. and Vins, O. (2003) 'Hospital Waste Treatment and Disposal in the General University Hospital-Current Situation and Future Challenges', *Indoor Built Environment*, Vol. 12, pp. 99-104
34. Benítez, S.O., Lozano-Olvera, G., Morelos, R.A. and de Vega, C.A. (2008) 'Mathematical modeling to predict residential solid waste generation', *Waste Management*, Vol. 28, Suppl. 1, pp. S7-S13

35. Benson, C.H., Barlaz, M.A., Lane, D.T., and Rawe, J.M. (2007) 'Practice review of five bioreactor/recirculation landfills', *Waste Management* Vol. 27, pp. 13–29
36. Berger C, Savard G and Wizere A. (1999) 'EUGENE: an optimisation model for integrated regional solid waste management planning', International Journal of Environmental Pollution Vol. 12, No.2/3, pp. 280–307
37. Birpınar, M. E., Bilgili, M. S. and Erdoğan, T. (2009) 'Medical waste management in Turkey: A case study of Istanbul', *Waste Management*, Vol. 29, pp. 445-448
38. Bjorklund, A., Dalemo, M., and Sonesson, U. (1999) 'Evaluating a municipal waste management plan using ORWARE', *Journal of Cleaner Production* 7, 271–280
39. Blakey, N.C., Bradshaw, K., Reynolds, P., and Knox, K. (1997) 'Bio-reactor landfill-a field trial of accelerated waste stabilisation', Proceedings Sardinia 97, Sixth International Landfill Symposium, Vol. I, CISA, Cagliari. pp. 375–386
40. Blenkharn, J.I. (2008) 'Standards of clinical waste management in hospitals-A second look', *Public Health*, Vol. 121, pp. 540-545
41. Boender, C.G.E., Grann, J.G., and Lootsma, F.A. (1989) 'Multi criteria decision analysis with fuzzy pairwise comparison', *Fuzzy Sets and Systems* Vol. 29, pp. 133–143
42. Bolaños, R., Fontela, E., Nenclares, A. and Pastor, P. (2005) 'Using interpretive structural modelling in strategic decision-making groups', *Management Decision*, Vol. 43, No. 6, pp. 877-895
43. Bozbura, F.T., Beskese, A. and Kahraman, C. (2007) 'Prioritization of human capital measurement indicators using fuzzy AHP', *Expert Systems with Applications*, Vol. 32, No.4, pp. 1100–1112
44. Brans, J.P., Macharis, C., Kunsch, C.P.L., Chevalier, A. and Schwaninger, M. (1998) 'Combining multicriteria decision aid and system dynamics for the control of socio-economic processes. An iterative real-time procedure', *European Journal of Operational Research* Vol. 109, pp.428–441
45. Brent, A.C., Rogers, D.E.C., Ramabitsa-Siimane, T.S.M. and Rohwer, M.B. (2007) 'Application of the analytical hierarchy process to establish health care waste management systems that minimise infection risks in developing countries', *European Journal of Operational Research* Vol. 181, No.1, pp. 403–424.
46. Bruner, P.H. and Ernst, W.R. (1986) 'Alternative Methods for the Analysis of Municipal Solid Waste', *Waste Management & Research*, Vol. 4 no. 1 147-160
47. Büyüközkan G., (2009) 'Determining the mobile commerce user requirements using an analytic approach', *Computer Standards & Interfaces*, Vol. 31, pp. 144–152
48. Büyüközkan, G., Ertay, T., Kahraman,C. and Ruan, D. (2004) 'Determining the importance weights for the design requirements in house of quality using fuzzy analytic network approach', *International Journal of Intelligent Systems* Vol. 19, No.5, pp. 443–461
49. Büyüközkan, G. (2004) 'Multi criteria decision-making for e-marketplace selection', *Internet Research: Electronic Networking Applications and Policy* Vol. 14, No2, pp. 139–154
50. Calvo, F., Moreno, B., Zamorano, M., and Szanto, M. (2005) 'Environmental diagnosis methodology for municipal waste landfills', *Waste Management* Vol. 25, pp. 768–779
51. Caruso, C., Colorni, A. and Paruccini, M. (1993) 'The regional urban solid waste management system: A modelling approach', *European Journal of Operational Research* Vol.70, pp. 16–30.

52. Cedzynska, K., Kolacinski, Z., Izydorczyk, M. and Sroczynski, W. (1999) 'Plasma vitrification of waste incinerator ashes', In: International Ash Utilization Symposium, Centre for Applied Energy Research, University of Kentuky
53. Census of India (2001) http://www.censusindia.gov.in/default.aspx (Last Accessed June 14, 2010 )
54. Chaerul, M., Tanaka, M. and Shekdar, A.V. (2008) 'A system dynamics approach for hospital waste management', *Waste Management*, Vol. 28, No. 2, pp. 442–449
55. Chan, F.T.S. and Kumar, N. (2007) ' Global supplier development considering risk factors using fuzzy extended AHP-based approach', *Omega*, Vol. 35, No.4, pp. 417–431
56. Chang, D.Y. (1992) '*Extent analysis and synthetic decision, optimization techniques and applications*', World Scientific, Singapore, pp. 1-352
57. Chang, D.Y. (1996) 'Applications of the extent analysis method on fuzzy AHP', *European Journal of Operational Research*, Vol. 95, No.3, pp. 649–655
58. Chang N-B., Chang Y.H. and Chen Y.L. (1997) 'Cost–effective and workload balancing operation in solid waste management systems', ASCE- *Journal of Environmental Engineering* Vol. 123, No.2, pp. 178–90
59. Chang, N-B., Davila, E., Dyson, B. and Brown, R. (2005) 'Optimal design for sustainable development of a material recovery facility in a fast-growing urban setting', *Waste Management*, Vol. 25, pp. 833–46.
60. Chang, N.-B., Shoemaker, C. A., and Schuler, R. E. (1996). ,Solid waste management systems analysis with air pollution and leachate impact limitations', *Waste Management & Research*, Vol. 14, pp. 463–481
61. Chang, N.B., Wang, S.F. (1996) 'Solid waste management system analysis by multiobjective mixed integer programming model', *Journal of Environmental Management*, Vol. 48, pp. 17–43
62. Chang, N., and Wang, S.F. (1997a) 'A fuzzy goal programming approach for the optimal planning of metropolitan solid waste management systems', *European Journal of Operational Research* Vol. 99, pp. 303–321
63. Chang, N., and Wang, S.F. (1997b) 'A fuzzy interval multi-objective mixed integer programming approach for the optimal planning of solid waste management systems', *Fuzzy Sets and Systems* Vol. 89, pp. 35–60
64. Chang, N.-B., and Wei, Y.L. (1999) 'Strategic planning of recycling dropoff stations and collection network by multiobjective programming', *Environmental Management* Vol. 24 No. 2, pp. 247–263
65. Chang, Y.H., and Chang, N., (1998) 'Optimization analysis for the development of short team solid waste management strategies using presorting process prior to incinerators', *Resources, Conservation and Recycling* Vol. 24, pp. 7–32
66. Charnpratheep, K., Zhou, Q. and Garner, B. (1997) 'Preliminary landfill site screening using fuzzy geographical information systems', *Waste Management and Research*, Vol.15, No.2, pp. 197–215
67. Chen, H.W. and Chang, N.B. (2000) 'Prediction analysis of solid waste generation based on grey fuzzy dynamic modeling', *Resources Conservation and Recycling*, Vol. 29, pp. 1–18

68. Chen, X., Lupi, F., He, G. and Liu, J. (2009) 'Linking social norms to efficient conservation investment in payments for ecosystem services', *Proceedings of the National Academy of Sciences* Vol. 106, pp. 11812–7
69. Chen, Y.R. (2000) 'Discussion of medical and industrial waste treatment policy', *Chinese Journal of Public Health* Vol. 19, No.4, pp. 303–308
70. Chen, Z. Li. H. and Wong, C. T. C. (2005) 'Environal planning: analytic network process model for environmentally conscious construction planning', *Journal of Construction Engineering and Management* Vol.131, No.1, pp. 92-101
71. Cheng, E.W. L. and Li, H. (2005) 'Analytic network process applied to project selection', *Journal of Construction Engineering and Management* Vol. 131, No.4, pp. 459-466
72. Cheng, S., Chan, C.W. and Huang, G.H. (2003) 'An integrated multi-criteria decision analysis and inexact mixed integer linear programming approach for solid waste management', *Engineering Applications of Artificial Intelligence,* Vol. 23 pp. 543-554
73. Chu, J.P., Hwang, I.J., Tzeng, C.C., Kuo, Y.Y. and Yu, Y.J. (1998) 'Characterization of vitrified slag from mixed medical waste surrogates treated by a thermal plasma system', *Journal of Hazardous Mater*ials, Vol. 58, pp.179–194
74. Chung, S.S. and Carlos, W. H. Lo. (2003) 'Evaluating sustainability in waste management: the case of construction and demolition, chemical and clinical wastes in Hong Kong', *Resources, Conservation and Recycling* Vol. 37, pp. 119–145
75. Clift, R., Doig, A. and Finnveden, G. (2000) 'The application of life cycle assessment to integrated solid waste management', *Trans IChemE* Vol. 78 (B), pp.279–287
76. Coker, A., Sangodoyin, A., Sridhar, M., Booth, C., Olomolaiye, P. and Hammond, F. (2009) 'Medical waste management in Ibadan, Nigeria: Obstacles and prospects', *Waste Management*, Vol. 29, pp. 804-811.
77. Cointreau, S.J. (1982) 'Environmental Management of Urban Solid Wastes in Developing Countries', *Urban Development Technical Paper*, No. 5, Washington DC, World Bank.
78. Corral-Verdugo, V. (1997) 'Dual 'Realities' of conservation behavior: self-reports vs observations of re-use and recycling behavior', *Journal of Environmental Psychology* Vol. 17, pp. 135–145
79. Corral-Verdugo, V. (2003) 'Situational and personal determinants of waste control practices in northern Mexico: a study of reuse and recycling behaviors', *Resources, Conservation and Recycling* Vol. 39, pp. 265-281
80. Costi, P., Minciardia, R., Robba, M., Rovatti, M., and Sacilea, R. (2004) 'An environmentally sustainable decision model for urban solid waste management', *Waste Management*, Vol. 24, pp. 277–295
81. Coutinho, M., Rodrigues, R., Duwel, U., Papke, O., Borrego, C. and Schroder, H. (2000) 'The DG European dioxin emission inventory-stage II: characterization of the emissions of 2 hospitals waste incinerators in Portugal', *Organohalogen Compounds* Vol. 46, pp. 287-290.
82. CPCB (1999) '*Status of solid waste generation, collection, treatment and disposal in metro cities*', Central Pollution Control Board, Delhi.
83. CPCB (Central Pollution Control Board) (2000) '*Management of Municipal Solid Waste Delhi*', Central Pollution Control Board

84. CPHEEO (2000) '*Manual on municipal solid waste management*', Central Public Health and Environmental Engineering Organization, Ministry of Urban Development, New Delhi.
85. Das, D., Srinivasu, M. and Bandyopadhyay, M. (1998) 'Solid state acidification of vegetable waste', *Indian Journal of Environmental Health,* Vol. 40, No.4, pp. 333–342
86. Da Silva, C. E., Hoppe, A. E., Ravanello, M. M. and Mello, N. (2005) 'Medical wastes management in the south of Brazil', *Waste Management*, Vol. 25, pp. 600-605
87. Daskalopoulos, E., Badr, O. and Probert, S. D. (1997) 'Economic and environmental evaluations of waste treatment and disposal technologies for municipal solid waste', *Applied Energy,* Vol. 58, No. 4, pp.209-255
88. Daskalopoulos, E., Badr, O. and Probert, S. D. (1998) 'An integrated approach to municipal solid waste management', *Resources, Conservation and Recycling*, Vol. 24, pp. 33–50
89. Davila, E., Chang, N-B. and Diwakaruni, S. (2005) 'Landfill space consumption dynamics in the Lower Rio Grande Valley by grey integer programming-based games', *Journal of Environmental Management*, Vol. 75, pp. 353–65
90. de Keyser, W. and Peeters, P. (1996) 'A note on the use of PROMETHEE multicriteria methods', *European Journal of Operational Research*, Vol. 89, pp. 457–461.
91. Delbecq, A.L., Van de Ven, A.H. and Gustafson, D.H. (1975) *Group Techniques for Program Planning: A Guide to Nominal Group and Delphi Processes*, Scott, Foresman and Company, Glenview, Illinois.
92. Delhi Pollution Control Committee < http://dpcc.delhigovt.nic.in/act_bmw.htm> Last accessed August 25, 2008
93. Demirtas, E. A. and Üstün, Ö. (2008) 'An integrated multiobjective decision making process for supplier selection and order allocation', *Omega* Vol. 36, pp.76 – 90
94. Derksen, L. and Gartrell, J. (1993) 'The social context of recycling', *American Sociological Review*, Vol. 58, pp.434-42
95. DeYoung, R. (1984) 'Motivating people to recycle: The use of incentives', *Resource Recycling* Vol. 42, pp. 14–15
96. De Young, R. (1986) 'Some psychological aspects of recycling: The structure of conservation satisfactions', *Environment and Behavior,* Vol. 18, pp.435–449
97. De Young R. (1991) 'Some psychological aspects of living lightly: desired lifestyle patterns and conservation behavior', *Journal of Environmental Systems,* Vol. 20, pp. 215-27
98. Dey, P.K. (2002) 'An integrated assessment model for cross-country pipelines', *Environmental Impact Assessment Review*, Vol. 22, pp. 703–721
99. Diaz, R. and Warith, M. (2006) 'Life-cycle assessment of municipal solid wastes: development of the WASTED model', *Waste Management*, Vol. 26, pp. 886–901
100. Diaz, L.F., Savage, G.M. and Eggerth, L.L. (2005) 'Alternatives for the treatment and disposal of healthcare wastes in developing countries', *Waste Management*, Vol.25, pp. 626–637
101. Diaz, L.F., Eggerth, L.L., Enkhtsetseg, Sh. And Savage, G.M. (2008) 'Characteristics of healthcare wastes', *Waste Management,* Vol. 28, No. 7, pp. 1219-1226
102. Dongqing, Z., Pinjing, H., Liming,S., Taifeng,J. and Jingyao, H. (2008) 'Biodrying of municipal solid waste with high water content by combined hydrolytic-aerobic technology', *Journal of Environmental Sciences* Vol. 20, pp. 1534–1540

103. Douglass, M. (1992) 'The political economy of urban poverty and environmental management in Asia: access, empowerment and community based alternatives', Environment and Urbanization Vol. 4, No. 2, pp. 9-32
104. Duncan, A.P. (1999) 'What is source reduction? A critique and comparative analysis of Polish and American students', *Environmental Management*, Vol. 23, pp. 495-505
105. Ebreo, A. and Vining, J. (2000) 'Motives as predictors of the public's attitudes toward solid waste issues', Environmental Management, Vol. 25, No. 2, pp. 153–168
106. Emery, A., Davies, A., Griffiths, A. and Williams, K. (2007) 'Environmental and economic modelling: a case study of municipal solid waste management scenarios in Wales', Resources Conservation and Recycling, Vol. 4, No.3, pp. 244–263
107. Englehardt, J.D. and Lund, J.R. (1990) 'Economic analysis of recycling for small municipal waste collectors', *Journal of Resource Management and Technology* Vol. 18, No. 2, pp. 84–96
108. Environment Canada (2000) '*Options for integrated municipal solid waste diversion*', Downsview, Ontario, Canada: Environmental Protection Services, Environment Canada.
109. EPIC and CSR (2000) 'Integrated Solid Waste Management Tools: Measuring the Environmental Performance of Waste Management Systems', Environment and Plastics Industry Council and Corporations supporting recycling
110. Erdogmus, S., Aras, H. and Koc, E. (2006) 'Evaluation of alternative fuels for residential heating in Turkey using analytic network process with group decision making', *Renewable and Sustainable Energy Reviews* Vol. 10, No.3, pp. 269-279
111. Eriksson, O., Frostell, B., Björklund, A., Assefa, G., Sundqvist, J., Granath, J., Carlsson, M., Baky, A. and Thyselius, L. (2002) 'ORWARE – a simulation tool for waste management', *Resources, Conservation and Recycling* Vol.36, pp. 287–307
112. ERRA, (1999) 'The Case for Integrated Waste Management, a briefing paper', European Recovery and Recycling Association
113. Esmaili, H. (1972) 'Facility selection and haul optimization model', *Journal of the Sanitary Engineering Division*, ASCE, pp.1005–1021
114. Everett, J.W. and Modak, A.R. (1996) 'Optimal regional scheduling of solid waste systems. I: model development', *Journal of Environmental Engineering*, Vol. 9, pp.785–792
115. Fabricino, M. (2001) 'An integrated program for municipal solid waste management', *Waste Management and Research*, Vol.19, pp.368–379
116. Faisal, M.N. (2010) 'Sustainable supply chains: A study of interaction among the enablers', *Business Process Management Journal*, Vol. 16, No. 3
117. Faisal, M. N. and Rahman, Z. (2008) 'E-government in India: modelling the barriers to its adoption and diffusion', *Electronic Government, An International Journal*, Vol. 5, No. 2, pp. 181-202
118. Faisal, M.N., Banwet, D.K. and Shankar, R. (2007a) 'Supply chain risk management in SMEs: analyzing the barriers', *International Journal of Management and Enterprise Development*, Vol. 4, No. 5, pp. 588-607
119. Faisal, M.N., Banwet, D.K. and Shankar, R. (2007b) 'Supply chain risk management in SMEs: analyzing the barriers', *International Journal of Management and Enterprise Development*, Vol. 4, No. 5, pp. 588-607

120. Faisal, M. N., Banwet, D. K. and Shankar, R. (2007c) 'Supply Chain Agility: Analysing the Enablers', *International Journal of Agile Systems and Management,* Vol. 2 No. 1, pp. 76-91
121. Faisal, M. N. and Banwet, D. K. (2009) 'Analyzing Alternatives for Information Technology Outsourcing Decision: An Analytic Network Process Approach', *International Journal of Business Information Systems,* Vol. 4, No. 1, pp. 47-62
122. Faisal, M.N., Khan, S. and Farooqi, I.H. (Accepted) 'Analysis of interactions among the barriers to effective hospital waste management', *International Journal of Behavioural and Healthcare Research,* Vol. X, No. Y.
123. Ficarella, A., Laforgia, D. (2000) 'Numerical simulation of flowfield and dioxins chemistry for incineration plants and experimental investigation', *Waste Management,* Vol. 20, pp. 27–49
124. Finnveden, G. (1999) 'Methodological aspects of life cycle assessment of integrated solid waste management systems', *Resources, Conservation and Recycling* Vol. 26, pp. 173–187
125. Fiorucci, P., Minciardi, R., Robba, M., and Sacile, R. (2003) 'Solid waste management in urban areas: development and application of a decision support system', *Resources Conservation and Recycling* Vol. 37, pp. 301–328
126. Flintoff, F. (1984) 'Management of Solid Waste in Developing Countries', *World Health Organization South- East Asia Series,* No. I, New Delhi.
127. Forman, E.H. (1998) *Decision by Objectives,* McLean.
128. Franka, E., El-Zoka, A. H., Hussein, A. H., Elbakosh, M. M., Arafa, A. K. and Ghenghesh, K. S. (2009) 'Hepatitis B virus and hepatitis C virus in medical waste handlers in Tripoli, Libya', *Journal of Hospital Infection,* Vol. 72, No. 3, pp. 258-261
129. Fu,H. P., Ho, Y.C., Chen, R.C.Y., Chang, T. H., and Chien, P.H. (2006) 'Factors affecting the adoption of electronic marketplaces; A fuzzy AHP analysis' *International Journal of Operations & Production Management,* Vol. 26, No. 12, pp. 1301-1324
130. Fuertes, L. (1974) 'Solid Waste Management: equitity trade off models', *Journal of the Urban Planning and Development Division,* ASCE , pp. 155–171
131. Furedy, C. (1990) 'Social aspects of solid waste recovery in Asian cities', *Environmental Sanitation Reviews,* Vol. 30, pp. 2-52. ENSIC, Asian Institute of Technology, Bangkok
132. Furedy, C. (1992) 'Garbage: exploring the non-conventional options in Asian cities', *Environment and Urbanization* Vol. 4, No.2, pp. 42-54
133. Furuichi, T. (ed) (1999) 'Planning of solid waste management', Kyouritsu, Tokyo, pp. 74 (in Japanese).
134. Fu, S.Q. (1998) Management of medical waste. *Bimonthly Journal of Research and Evaluation* Vol. 22 No.5, pp. 100–104
135. Gabola, S. (1999) 'Towards a sustainable basis for the EU Packaging and Packaging Waste Directive', In: ERRA Symposium, Brussels
136. GAIA, (2000) 'Waste Incineration a Dying Technology Quoting', USEPA, p. 18.
137. Garrod, G.D. and Willis, K. (1998) 'Estimating lost amenity due to landfill waste disposal', *Resources, Conservation and Recycling* Vol. 22, pp. 83–95
138. Giroletti, E. and Lodola, L. (1994) '*Technologies for Environmental Cleanup: Toxic and Hazardous Waste Management*', In: Avogadro, A., Ragaini, R.C. (Eds.), Kluwer Academic, Brussels.

139. Gotoh, S. (1989) 'Issues and factors to be considered for improvement of solid waste management in Asian metropolises', *Regional Development Dialogue* Vol. 10, No.3, pp.1-12
140. Gottinger, W.H. (1988) 'Theory and methodology: a computational model for solid waste management with application', *European Journal of Operational Research*, Vol. 35, pp. 350–364
141. Guitouni, A. and Martel, J. (1998) 'Tentative guidelines to help choosing an appropriate MCDA method', *European Journal of Operational Research* Vol. 109, pp. 501–521
142. Gupta, S. and Boojh, R. (2006) 'Report: Biomedical waste management practices at Balrampur Hospital, Lucknow, India', *Waste Management & Research*, Vol. 24, pp. 584-591
143. Gupta, S., Mohan, K., Prasad, R., Gupta, S. and Kansal, A. (1998) 'Solid waste management in India: options and opportunities', *Resources, Conservation and Recycling*, Vol.24. pp. 137–154
144. Gu, Y.J. and Pan, J.C., (1999) 'The Question of the infectious waste and management countermeasure', *Highlight of Industrial Pollution Control* Vol. 135, No. 12, pp. 138–151
145. Hamalainen, R.P. and Seppalainen, T.O. (1986) 'The analytic network process in energy policy planning', *Socio-Economic Planning Science* Vol. 20, No.6, pp. 399–405
146. Harrison, K.W., Dumas, R.D., Solano, E., Barlaz, M.A., Brill, E.D. and Ranjithan, S.R. (2001) 'Decision support for life cycle based solid waste management', *Journal of Computing in Civil Engineering*, pp. 44–58
147. Harvie, M. and Jaques, P. (2003) 'Public awareness and the environment: how do we encourage environmentally responsible behaviour?' *Water Science and Technology: Water Supply* Vol. 3, No. 3, pp. 247–254.
148. Hasit, Y. and Warner, D.B. (1981) 'Regional solid-waste planning with Wrap', *Journal of Environmental Engineering Division*, ASCE, Vol. 107, pp. 511–25
149. Healthcare without Harm (HCWH) (2004), News Release, July 7, 2004.
150. Heinen, J.T. (1995) 'A review of, and research suggestions for, solid-waste management issues: the predicted role of incentives in promoting conservation behavior, *Environmental Conservation* Vol. 22, No. 2, pp. 157–166
151. Helms, B.P. and Clark, R.M. (1971) 'Locational models for solid waste management', *Journal of Urban Planning and Development Division*, ASCE, Vol. 97, pp.1–13
152. Henry, G. and Heinke, G.W. (1996) *Environmental Science and Engineering*, second ed. Prentice-Hall, Englewood, NJ
153. Hines, J.M., Hungerford, H.R. and Tomera, A.N. (1987) 'Analysis and synthesis of research on responsible environmental behavior: a meta-analysis', *Journal of Environmental Education*, Vol. 18, pp.1-8
154. Hokkanen, J. and Salminem, P. (1997) 'Choosing a solid waste management system using multicriteria decision analysis', *European Journal of Operational Research* Vol. 98, pp. 19–36
155. Hristovski, K., Olson, L., Hild, N., Peterson, D. and Burge, S. (2007) 'The municipal solid waste system and solid waste characterization at the municipality of Veles, Macedonia', *Waste Management* Vol. 27, No. 11, pp.1680–1689

156. Hsiao, K.W., Yang, Y.C., Hong, J.J., Tam, S.C. and Tan, C.H. (2004) 'A study of the disposal ways and fees of medical waste in Taiwan hospitals', *Journal of Healthcare Management,* Vol. 5, No.1, pp. 79–100
157. Hsu , P.F., Wu , C. R. and Li, Y. T. (2008) 'Medical waste disposal management by using the analytic hierarchy process and sensitivity analysis', *Waste Management* Vol. 28, No. 8, pp.1386-1394
158. Huang, G.H, Baetz, B.W., Patry, G.G. and Terluk, V. (1997) 'Capacity planning for an integrated waste management system under uncertainty: a North American case study', Waste Management & Research Vol. 15, No.5, pp. 523–46
159. Huang, G.H., Baetz, B.W. and Patry, G.G. (1998) 'Trash-flow allocation: planning under uncertainty', *Interfaces*, Vol. 28, No.6, pp.36–55
160. Hung, M.L., Ma, H. and Yang, W.F. (2007) 'A novel sustainable decision making model for municipal solid waste management', *Waste Management* Vol. 27, No.2, pp. 209–219
161. Jacobs, H. E. and Bailey, J. S. (1982) 'Evaluating participation in a residential recycling program', *Journal of Environmental Systems* Vol.12, pp. 141–152
162. Jacobs, H. E., J. S. Bailey, and J. I. Crews. (1984) 'Development and analysis of a community-based resource recovery program', *Journal of Applied Behavior Analysis* Vol. 17, pp. 127–145
163. Jacobs, T. and Everett, J. W. (1992) 'Optimal scheduling of landfill operations incorporating recycling', *Journal of Environmental Engineering,* Vol. 118, No. 3, pp. 420–429
164. Jacquet-Lagreze, E. and Siskos, Y. (1982) 'Assessing a set of additive utility functions for multicriteria decision-making, the UTA method', *European Journal of Operational Research* Vol. 10, No.2, pp. 151–164
165. Jacquet-Lagreze, E. and Siskos, Y. (2001) 'Preference disaggregation: 20 years of MCDA experience', *European Journal of Operational Research,* Vol. 130, pp. 233–245.
166. Jang , Y-C., Lee, C., Yoon , O-S. and Kim, H. (2006) 'Medical waste management in Korea', *Journal of Environmental Management,* Vol. 80, pp. 107-115
167. Jharkaria, S., and Shankar, R. (2007) 'Selection of logistics service provides: An analytic network process approach', *Omega,* Vol. 35, No. 3, pp. 274-289
168. Jenkins, L. (1982) 'Parametric mixed integer programming—an application to solid-waste management', *Management Science*, Vol. 28, pp. 1270–1284
169. Jinbo, M. (1997) 'Application of analytical hierarchy process method for selecting the optimal environmental engineering scheme', *Advances in Environmental Science*, Vol. 4, pp. 33-40
170. Joos, W., Carabias, V., Winistoerfer, H. and Stuecheli, A. (1999) ' Social aspects of public waste management in Switzerland', *Waste Management,* Vol. 19, pp. 417–425
171. Joseph, K. (2002) 'Perspectives of solid waste management in India', International Symposium on the Technology and Management of the Treatment & Reuse of the Municipal Solid Waste, Shanghai, China
172. Juwen H, Guangming, L., Hua, W. and Liaoliao, C. (2007) 'Analytic hierarchy process-based evaluation of recycling solid waste in Shanghai', *Journal of Tongji University(Natural Science),* Vol. 8, pp. 1090-1094

173. Kahraman, C. and Kaya, İ. (2010) 'A fuzzy multicriteria methodology for selection among energy alternatives', *Expert Systems with Applications*, Vol. 37, No. 9, pp: 6270-6281
174. Kaiser B, Eagan, P.D. and Shaner, H. (2001) 'Solutions to health care waste : life – cycle thinking and "green" purchasing', *Environmental Health Perspectives* , Vol. 109, No.3, pp. 205-207
175. Karademir, A. (2004) 'Health risk assessment of PCDD/F emissions from a hazardous and medical waste incinerator in Turkey', *Environment International Journal*, Vol. 30, pp. 1027-1038
176. Karagiannidis, A., Papageorgiou, A., Perkoulidis, G., Sanida, G. and Samaras, P. (2010) 'A multi-criteria assessment of scenarios on thermal processing of infectious hospital wastes: A case study for Central Macedonia', *Waste Management* Vol. 30, pp. 251–262.
177. Karamouz, M., Zahraie, B., Kerachian, R., Jaafarzadeh, N., and Mahjouri, N. (2007) 'Developing a master plan for hospital solid waste management: a case study', *Waste Management*, Vol. 27, pp. 626–638
178. Katzev, R. and Johnson, T.R. (1984) 'Comparing the effects of monetary incentives and foot-in-the-door strategies in promoting residential electricity conservation', *Journal of Applied Social Psychology*, Vol. 14, pp.12-27
179. Katzev, R., Blake, G., and Messer, B. (1993) 'Determinants of participation in multi-family recycling programs', *Journal of Applied Social Psychology* Vol. 23, pp. 374–385
180. Kaufmann, A., and Gupta, M.M. (1991) *Introduction to Fuzzy Arithmetic Theory and Applications*, Van Nostrand Reinhold, New York
181. Keeney, R., and Raiffa, H. (1976) 'Decisions with Multiple Objectives: Preferences and Value Tradeoffs', Wiley, New York
182. Keller, J.M., and Tahani, H. (1992) 'Implementation of conjunctive and disjunctive fuzzy logic rules with neural networks', *International Journal of Approximate Reasoning*, Vol. 6, pp. 221-240
183. Khan, S. (2006) 'Occupational risks to primary waste collectors in Municipal Corporation of Delhi', International Conference: Environmental Management Practices in India: Issues, Imperatives &Implications, Udaipur, India
184. Khan, S. and Faisal, M.N. (2008) 'An analytic network process model for municipal solid waste disposal options', *Waste Management*, Vol. 28, pp. 1500–1508
185. Khan, S., Farooqi, I.H. and Faisal, M.N. (2008) 'Analysis of interactions among the barriers to effective hospital waste management in India', The 23rd International Conference on Solid Waste Management, Philadelphia, USA
186. Khasnabis, S., Alsaidi, E., Liu, L. and Ellis, R.D. (2002) 'Comparative study of two techniques of transit performance assessment: AHP and GAT', *Journal of Transportation Engineering*, Vol. 128, No. 6, pp. 499–508
187. Kirca J, and Erkip N. (1988) 'Selecting transfer station locations for large solid waste systems', *European Journal of Operations Research*, Vol. 38, pp.339–49
188. Koushki, P.A. and Alhumoud, J.M. (2002) 'Evaluation of reported and measured compositions of household solid waste in Kuwait', *Practical Periodical of Hazardous, Toxic, and Radioactive Waste Management*, ASCE Vol. 6, No. 3, pp. 204–8
189. Kowalewski, R., Reid Lea, W. and Tittebaum, M. (1999) 'A standardized data reporting methodology for long-term integrated municipal solid waste management—a case study', *Journal of Solid Waste Technology and Management* Vol. 26, No.1, pp. 26–35

190. Kulak, O. and Kahraman ,C. (2005) 'Fuzzy multi-attribute selection among transportation companies using axiomatic design and analytic hierarchy process', *Information Sciences* Vol. 170 , pp. 191–210
191. Kumar, S. and Gaikwad, S.A. (2004) 'municipal solid waste management in Indian urban centers: an approach for betterment', *Urban Development Debates in the New Millennium*, (Ed.) K.R. Gupta, Atlantic Publishers & Distributors, New Delhi, pp.100-111.
192. Kumar, S., Gaikwad, S.A., Sehkdar, A.V., Kshirsagar P.S. and Singh, R.N. (2004) 'Estimation method of national methane emission from solid waste landfills', *Atmospheric Environment* , Vol. 38, pp. 3481–7
193. Kwong, C.K. and Bai, H. (2003) 'Determining the importance weights for the customer requirements in QFD using a fuzzy AHP with an extent analysis approach', *IIE Transactions*, Vol. 35 pp. 619–626
194. Lakshmi, K. (2003) 'Norms Given by the go-by in Govt, Hospitals', *The Hindu* online edition of India's National Newspaper, Monday, 24 March, 2003
195. Last, M. J. ('*Public health and preventive medicine*'(1986), 12th Edition, Maxcy-Rosenau, East Norwalk, Connecticut: Appleton-Century-Craft, pp. 845
196. Leão, S., Bishop, I. and Evans, D. (2001) 'Assessing the demand of solid waste disposal in urban region by urban dynamics modelling in a GIS environment', *Resources, Conservation and Recycling*, Vol. 33, pp. 289–313
197. Leão, S., Bishop, I. and Evans, D. (2004) 'Spatial–temporal model for demand and allocation of waste landfills in growing urban regions', *Computers, Environment and Urban Systems* Vol. 28, pp. 353–385
198. Lee, H., Kim, C., Cho, H. and Park, Y. (2009) 'An ANP-based technology network for identification of core technologies: A case of telecommunication technologies', *Expert Systems with Applications*, Volume 36, No.1, pp. 894-908
199. Levy, J.K. and Taji, K. (2007) 'Group decision support for hazards planning and emergency management: A Group Analytic Network Process (GANP) approach', *Mathematical and Computer Modelling* Vol. 46, pp. 906–917
200. Li, L., Shia, Z-H., Yin,W., Zhua, D., Ng, S.L., Caia,C-F. and Lei, A-L. (2009) 'A fuzzy analytic hierarchy process (FAHP) approach to eco-environmental vulnerability assessment for the Danjiangkou reservoir area, China', *Ecological Modelling,* Vol. 220, pp. 3439–3447
201. Lingard, H. (2002) 'The effect of first aid training on Australian construction workers' occupational health and safety knowledge and motivation to avoid work-related injury or illness', *Construction Management Economics* Vol. 20, pp. 263–273
202. Li, S. (2003) 'Recycling behavior under China's social and economic transition, the case of metropolitan Wuhan', *Environment and Behavior* Vol. 35, No.6, pp.784–801
203. Liu, W. (2003) *Quantitative analysis for public administration*, Wuhan: Wuhan Press (in Chinese)
204. Lund, J. (1990).Least-cost scheduling of solid waste recycling. Journal of Environmental Engineering, Vol. 116, pp. 182–197
205. Lyons, E. and Breakwell, G.L. (1994) 'Factors predicting environmental concern and indifference in 13-16 year-olds', *Environment and Behavior*, Vol. 26, pp. 223-38
206. MacDonald, M.L. (1996a) 'A Multi-attribute spatial decision support system for solid waste planning', *Computers, Environment, and Urban Systems* Vol. 20, No.1, pp. 1–17

207. MacDonald, M.L. (1996b) 'Solid waste management models: a state of the art review', *Journal of Solid Waste Technology and Management*, Vol. 23, No. 2, pp. 73–83
208. McDonald, S. and Oates, C. (2003) 'Reasons for non-participation in a kerbside recycling scheme', *Resource Conservation and Recycling*, Vol. 9, No.4, pp.369–385
209. Madeira, C.M.P. (1995) 'Tratamento de Residuous Hospittalaries e Saude', *Publica. Associacao Portuguesa de Infeccao Hospitalar*, Liboa.
210. Mainieri, T., Barnett, E., Valdero, T., Unipan, J. and Oskamp, S. (1997) 'Green buying the influence of environmental concern on consumer behavior', *The Journal of Social Psychology*, Vol. 13, pp. 189-204
211. Manaf, L.A., Samah, M.A.A. and Zukki, N.I.M. (2009) 'Municipal solid waste management in Malaysia: Practices and challenges', *Waste Management*, Volume 29, No.11, pp. 2902-2906
212. Mandal, A. and Deshmukh, S.G. (1994) 'Vendor seletion using interpretive structural modelling (ISM)', *International Journal of Operations and Production Management*, Vol. 14, No. 6, pp.52-59
213. Manohar, D., Reddy, P.R., and Kotaih, B. (1998) 'Characterization of solid waste of a super speciality hospical – a case study', Indian Journal of Environmental Health, Vol. 40, No. 4, pp. 319–326
214. Marinković, N., Vitale, K., Holcer, N.J., Džakula, A. and Pavić, T. (2008) 'Management of hazardous medical waste in Croatia', *Waste management*, Vol. 28, No. 6, pp. 1049-1056.
215. Marowski, D.G. (1992) 'Environmental Viewpoints', Gale Research International Ltd.
216. Massouda, M. A, El-Fadelb, and M., Malak, A.A. (2003) 'Assessment of public vs private MSW management: a case study', *Journal of Environmental Management* Vol. 69, pp. 15–24
217. Mastro, F.L., and Mistretta, M. (2004) 'Cogeneration from thermal treatment of selected municipal solid wastes. A stoichiometric model building for the case study on Palermo', *Waste Management* Vol. 24, pp. 309- 317
218. Mato, R.R.A.M. and Kassenga, G.R. (1997) 'A study on problems of management of medical solid wastes in Dar es Salaam and their remedial measures', *Resources, Conservation and Recycling* Vol. 21, No.1, pp. 1–16.
219. Matsufuji, Y., Tachifuji, A., and Matsugu, H. (2005) 'Biodegradation process of municipal solid waste by semiaerobic landfill type', In: Proceedings Sardinia 2005, Tenth International Waste Management and Landfill Symposium. S. Margherita di Pula, Cagliari, Italy
220. MCD (2005). Municipal Corporation of Delhi. 'A report on the solid waste management in Delhi', National Workshop on Municipal Solid Waste Management: Sharing of Experiences and Lessons Learnt, New Delhi
221. McDougall, F., White, P., Franke, M., and Hindle, P. (2001) '*Integrated solid waste management: a life cycle inventory*', Blackwell Science, London
222. McIntyre, C., Kirschenman, M., and Seltveit, S. (1999) 'Applying decision support software in selection of division director', *Journal of Management in Engineering*, Vol. 15, No.2, pp. 86–92
223. McKenzie-Mohr, D. and Oskamp, S. (1995) 'Psychology and sustainability: an introduction', *Journal of Social Issues*, Vol. 51, pp. 1-14

224. Meade, L. M. and Sarkis, J. (1999). 'Analyzing organizational project alternatives for agile manufacturing processes', *International Journal of Production Research*, Vol. 37, No.2, pp. 241–261.
225. Meade, L. and Sarkis, J. (1998) 'Strategic analysis of logistics and supply chain management systems using the analytic network process', *Transportation Research* Part E Vol. 34, No.3, pp. 201–215.
226. Medical Waste Committee (MWC) (1994) 'Medical waste disposal', *Journal of Air & Waste Management Association*, Vol. 44, pp. 1176–1179.
227. Minehart, D. (2002) 'Effective siting of waste treatment facilities', *Journal of Environmental Economics and Management*, Vol. 43, pp. 303–324
228. Minglung, H., Wanfa, Y., Hwongwen, M., and Yamei, Y. (2006) 'A novel multiobjective programming approach dealing with qualitative and quantitative objectives for environmental management', *Ecological Economic*, Vol. 56 pp. 584–593.
229. Ministry of Environment and Forest (MoEF). (2010) moef.nic.in/downloads/public-information/Roadmap-Mgmt-Waste.pdf (Last Accessed June 15, 2010).
230. Morris, J. (1991) 'Source separation vs centralized processing: an avoided cost optimisation model provides some intriguing answers', *Journal of Resource Management and Technology*, Vol. 19, No.3, pp. 133–140
231. Morris, M. and Waldheim, L. (1998) 'Energy recovery from solid waste fuels using advanced gasification technology', *Waste Management* Vol. 18, pp. 557-564
232. Morrissey, A.J. and Browne, J. (2004a) 'Waste management models and their application to sustainable waste management', *Waste Management* Vol. 24, pp. 297–308
233. Morrissey, A.J. and Browne, J. (2004b) 'A methodology for community based waste management', *Journal of Solid Waste Technology and Management* Vol. 30, No.3, pp. 170-182
234. Motameni, R. and Falcone, T. (1990) 'The application of Martin Fishbein's theory of reasoned action in solid waste management and recycling', *Journal of Resource Management and Technology* Vol. 18, No.3&4, pp. 144–150
235. Mousseau, V., Slowinski, R. and Zielniewicz, P. (2000) 'A user-oriented implementation of the ELECTRE-TRI method integrating preference elicitation support', *Computers and Operations Research*, Vol. 27, pp.757–777
236. Muhlich, M., Scherrer, M. and Daschner, F.D. (2003) 'Comparison of infectious waste management in European hospitals', *Journal of Hospital Infection*, Vol. 55, pp. 260-268
237. Murtaza, M. B. (2003) 'Fuzzy-AHP application to country risk assessment' *American Business Review*, Vol. 21, No. 2, pp. 109-116
238. National Environmental Engineering Research Institute, (1999) Available from http/neeri.res.in (Last accessed 04/05/2010).
239. Nema, S.K. and Ganeshprasad, K.S. (2002) 'Plasma pyrolysis of medical waste', *Curr. Sci.* Vol. 83, pp. 271–278.
240. Niessen, W.R., Marks, C.H., and Sommerlad, R.E. (1996) 'Evaluation of gasification and novel thermal processes for the treatment of municipal solid waste', NREL/TP-430-21612, Report for the National Renewable Energy Laboratory, Golden CO
241. Nilsson-Djerf, J. and McDougall, F. (2000) 'Social factors in sustainable waste management', Warmer Bull, Vol. 73, pp. 18–20

242. Notification: Bio-medical Waste (Management and Handling) Rules, (1998) Ministry of Environment and Forests, GOI (E), part 3(ii), New Delhi
243. Ock, J.H., Han, S.H., Park ,H.K. and Diekmann, J.E. (2005) 'Improving decision quality: a risk-based go/no go decision for build-operates-transfer (BOT) projects', *Canadian Journal of Civil Engineering*, Vol. 32, pp. 517–532
244. Okoli, C. and Pawlowski, S.D. (2004) 'The Delphi method as a research tool: an example, design considerations and applications', *Information &Management* Vol. 42, pp. 15–29
245. Or, I. and Curi, K. (1993) 'Improving the efficiency of the solid waste collection system in Izmir, Turkey, through mathematical programming', *Waste Management and Research*, Vol. 11, pp. 297–311
246. Ozdemir, M.S. and Saaty, T. L. (2006) 'The unknown in decision making what to do about it', *European Journal of Operational Research*, Vol. 174, pp. 349–359
247. Pan, N.-F. 'Fuzzy AHP approach for selecting the suitable bridge construction method', (2008) *Automation in Construction* Vol. 17, pp. 958–965
248. Pan, T.Y. and Chen, J.L. (1997) 'A study on the treatment of the medical wastes', *Chia Nan Annual Bulletin* Vol. 23, pp. 96–107
249. Partovi, F.Y., Burton, J. and Banerjee, A. (1990) 'Application of analytic hierarchy process in operations management', *International Journal of Operations and Production Management*, Vol. 10, No.3, pp. 5–19
250. Patil, A.D. and Shekdar, A.V. (2001) 'Health-care waste management in India', *Journal of Environmental Management*, Vol. 63, pp. 211-220
251. Patil, G.V. and Pokhrel, K. (2005) 'Biomedical solid waste management in an Indian hospital: a case study', *Waste Management*, Vol. 25, pp. 592-599
252. Perlack R.D. and Willis, C.E. (1987) 'Multiobjective decision-making in waste-disposal planning—closure', *Journal of Environmental Engineering*, ASCE, Vol. 113, pp. 666–7
253. Petts, J. (2000) 'Municipal waste management: inequities and the role of deliberation', *Risk Analysis* Vol. 20, No. 6, pp. 821–832
254. Podar, M. (1993) 'New opportunities for re-use/recycling of wastes—the Yorktown refinery experience', In: Proceedings of Symposium on Environmental Planning and Development, pp. 264–71
255. Powell, J. (2000) 'The potential for using life cycle inventory analysis in local authority waste management decision making', *Journal of Environmental Planning and Management* Vol. 43, No.3, pp. 351–367
256. Premuzic, E.T., Lin, M.S. and Jin, J.Z. (1992) 'Developments in geothermal waste treatment biotechnology', *Geothermics*, Vol. 21, No. 5-6, pp. 891-899
257. Promentilla, M.A.B., Furuichi, T., Ishii, K. and Tanikawa, N. (2008) 'A fuzzy analytic network process for multi-criteria evaluation of contaminated site remedial countermeasures', *Journal of Environmental Management*, Vol. 88, No. 3, pp. 479-495
258. Promentilla, M.A.B., Furuichi, T., Ishii, K. and Tanikawa, N. (2006) 'Evaluation of remedial countermeasures using the analytic network process', *Waste Management*, Vol. 26, No. 12, pp. 1410–1421
259. Prüss, A, Giroult, E. and Rushbrook, P. (1999) '*Safe management of wastes from health-care activities*',WHO, Geneva

260. Pusch, R. (1998) 'Categorization of discontinuities for conceptual description of rock hosting repositories for hazardous waste', *Engineering Geology,* Vol. 49, pp. 177-183
261. Quaddusa, M.A. and Siddique, M.A.B. (2001) 'Modelling sustainable development planning: a multicriteria decision conferencing approach' *Environment International,* Vol. 27, pp. 89–95
262. Qureshi, M. E., Harrison, S. R., Wegener, M. K. (1999) 'Validation of multicriteria analysis models', *Agricultural Systems,* Vol. 62, No. 2, pp. 105-116
263. Qiu, Y.R. (2001) 'Question of medical waste disposal', *Taiwan Medical Journal* Vol. 44, No.5, pp. 49–50
264. Raman, B. (1995) 'A comparison of solid waste collection and disposal in Indian cities: the approaches of non-governmental organizations to solid waste management. Urban habitat: the environment of tomorrow', In: International Conference in Delft, The Netherlands, 15–17
265. Read, A. D., Phillips, P. and Robinson, G. (1997) 'Landfill as a future management option on England: the view of landfill operators', *Resource, Conservation and Recycling,* Vol. 20, pp. 183-205.
266. Refsgaard, K. and Magnussen, K. (2009) 'Household behaviour and attitudes with respect to recycling food waste experiences from focus groups', *Journal of Environmental Management* 90 760-771
267. Reinhardt, P.A. and Gordon, J.G. (1991) 'Infectious and Medical Waste Management', Lewis Publishers Inc., Michigan, USA.
268. Rich, L.A. (1986) 'Hazardous waste management: new rules are changing the game', *Chemical Week,* August, pp 26-50
269. Rogers, M. (2001) 'Engineering Project Appraisal', Blackwell Science, London
270. Roy, B. (1991) 'The outranking approach and the foundations of ELECTRE methods', *Theory and Decision* Vol. 31, No.1, pp. 49–73
271. Rueda-Manzanares, A., Aragon-Correa, J.A. and Sharma, S. (2008) 'The influence of stakeholders on the environmental strategy of service firms: the moderating effects of complexity, uncertainty and munificence', *British Journal of Management* Vol. 19, No.2, pp. 185–203.
272. Ruoyan, G., Lingzhong, X., Huijuan, L., Chengchao, Z., Jiangjiang, H., Yoshihisa, S., Wei, T. and Chushi, K. (2010) 'Investigation of health care waste management in Binzhou district, China', *Waste Management,* Vol. 30. No.2, pp.246-250.
273. Saaty, T.L. (2001) '*Decision making with dependence and feedback: the analytic network process*', RWS Publications, Pittsburgh, USA.
274. Saaty, T. L. (1999) '*Fundamentals of the ANP: ISAHP Proc*'. Kobe, Japan, 16
275. Saaty, T.L. (1996) '*Decision Making with Dependence and Feedback: The Analytic Network Process*', RWS Publications, Pittsburgh
276. Saaty, T.L. (1994) 'Theory and methodology: Highlights and critical points in the theory and application of the Analytic Hierarchy Process', *European Journal of Operational Research* Vol. 74, pp. 426-447
277. Saaty, T.L. (1980) '*The Analytic Hierarchy Process*', McGraw Hill Company
278. Sabour,M. R., Mohamedifard, A. and Kamalan, H. (2007) 'A mathematical model to predict the composition and generation of hospital wastes in Iran', Waste Management, Vol. 27, pp. 584-587

279. Sadiq, R., Khan, F.I. and Veitch, B. (2005) 'Evaluating offshore technologies for produced water management using GreenPro-I—a risk-based life cycle analysis for green and clean process selection and design', *Computers & Chemical Engineering*, Vol. 29, No.5, pp. 1023-1039
280. Sadiq, R., and Rodriguez, M.J. (2004) 'Fuzzy synthetic evaluation of disinfection by-products—a risk-based indexing system', *Journal of Environmental Management*, Vol. 73, No.1, pp. 1-13
281. Sadiq, R. and Tesfamariam, S. (2009) 'Environmental decision-making under uncertainty using intuitionistic fuzzy analytic hierarchy process', *Stochastic Environmental Research and Risk Assessment*, Vol. 23, No. 1, pp. 75- 92
282. Salhofer, S. (2000) 'Modelling commercial/industrial waste generation: a Vienna, Austria case study', *Waste Management and Research*, Vol. 18, pp. 269–282
283. Sage, A.P. (1977) '*Interpretive Structural Modeling: Methodology for Large-scale Systems*', New York: McGraw-Hill
284. Salminen, P., Hollanen, J. and Lahdelma, R. (19980 'Comparing multicriteria methods in the context of environmental problems', *European Journal of Operational Research* Vol. 104, pp. 485–496
285. Sandhu, T.S. and Singh, N. (2003)' A hazard going unnoticed – biological waste is a threat to the community at large', *The Tribune, Online edition*, Chandigarh, India, Monday, June 30, 2003
286. Sarkis, J. (1998) 'Theory and Methodology Evaluating environmentally conscious business practices', *European Journal of Operational Research* Vol. 107, pp. 159- 174
287. Sarkis, J., J. and Cordeiro J. (2001) 'Theory and Methodology -An empirical evaluation of environmental efficiencies and firm performance: Pollution prevention versus end-of-pipe practice', *European Journal of Operations Research* Vol. 135, pp. 102-113
288. Sarkis, J., Gonzalez-Torre, P. and Adenso-Diaz, B. (2010) 'Stakeholder pressure and the adoption of environmental practices: The mediating effect of training', *Journal of Operations Management* Vol. 28, No.2, pp. 163–176.
289. Saxena, J.P. and Vrat, P. S. (1992) 'Scenario building: A critical study of energy conservation in the Indian cement industry', *Technological Forecasting and Social Change*, Vol. 41, pp. 121-146
290. Schertenleib, R. and Meyer, W. (1992) 'Municipal Solid Waste Management in DC's: Problems and Issues; Need for Future Research', *IRCWD News*,_No. 26, Duebendorf, Switzerland
291. Schultz, P.W. (1999) 'Changing behavior with normative feedback interventions: a field experiment on curbside recycling', *Basic and Applied Social Psychology* Vol. 21, pp. 25–36
292. Scott, D. (1999) 'Equal opportunity, unequal results. Determinants of household recycling intensity', *Environment and Behavior*, Vol.31, pp. 267-90
293. Scott, D. and Willits, F.K. (1994) 'Environmental attitudes and behavior: a Pennsylvania survey', *Environment and Behavior* Vol. 26, pp.239-60
294. Sharma, H.D., Gupta, A.D. and Sushil. (1995) 'The objectives of waste management in India: A future inquiry', *Technological Forecasting and Social Change*, Vol. 48, No. 3, pp. 285–309.

295. Shaw, P.J. and Maynard, S.J. (2008) 'The potential of financial incentives to enhance householders' kerbside recycling behavior', *Waste Management* Vol. 28, pp. 1732–1741
296. Shekdar, A.V. (2009) Sustainable solid waste management: An integrated approach for Asian countries *Waste Management*, Vol. 29, No. 4, pp. 1438-1448
297. Shi, H., Peng, S.Z., Liu, Y. and Zhong , P. (2008) 'Barriers to the implementation of cleaner production in Chinese SMEs: government, industry and expert stakeholders' perspectives', *Journal of Cleaner Production*, Vol. 16, No.7, pp. 842-852
298. Shih, L.H. and Chang, H.C. ( 2001) ' A routing and scheduling system for infectious waste collection', *Environmental Modeling and Assessment* Vol. 6, pp. 261–269.
299. Shinee, E., Gombojav, E., Nishimura, A., Hamajima, N. and Ito, K. (2008) 'Healthcare waste management in the capital city of Mongolia', *Waste Management*, Vol. 28, pp. 435-444
300. Sidique, S. F., Lupi, F., and Joshi, S.V. (2010) 'The effects of behavior and attitudes on drop-off recycling activities', *Resources, Conservation and Recycling* Vol. 54, pp. 163–170
301. Simmons, D. and Widmar, R. (1990) 'Motivations and barriers to recycling: Toward a strategy for public education', *Journal of Environmental Education* Vol. 22, pp.13–18
302. Simon, H. (1976) '*Administrative Behaviour*', New York Free Press, New York.
303. Singh, S. (2001) 'Mismanaging hospital waste', *Economic and Political Weekly*, April, pp. 1297-1298
304. Singhal, S. and Pandey, S. (2001) 'Solid waste management in India: status and future directions', *TERI Information Monitor on Environmental Science*, Vol.6, No.6, pp 1-4
305. Siru, D., Pillay, M.S. and Sinha, K. (2006) 'A national approach to clinical waste management', *Journal of Solid Waste Technology and Management* Vol. 32, No. 4, pp.199-205
306. Siskos, Y. (1999) 'Intelligent multicriteria decision support: overview and perspectives', *European Journal of Operational Research*, Vol. 113, pp. 236–246.
307. Smith, D.G. and Baetz, B.W. (1991) 'A comprehensive costing methodology for the assessment of solid waste management alternatives', *Journal of Resource Management and Technology*, Vol.19, No.4, pp. 140–147
308. Soliman, S.M. and Ahmed. A. I. (2007) 'Overview of biomedical waste management in selected Governorates in Egypt: A pilot study' *Waste Management* 27, pp. 1920–1923
309. Srivastava, P.K., Kulshreshtha , K., Mohanty , C.S., Pushpangadan , P. and Singh, A. (2005) 'Stakeholder-based SWOT analysis for successful municipal solid waste management in Lucknow, India', *Waste Management* Vol. 25, pp. 531–537
310. Stegmann, R. (2002) 'Strategy for a sustainable landfill, planning, operation, aftercare', In: APLAS Proceedings, The 2$^{nd}$ Asia Pacific Landfill Symposium, Seoul, Korea, September, 25–28, pp. 56–66
311. Stern, P.C., Dietz, T. and Guagnano, G.A. (1995) 'The new ecological paradigm in social -psychological context', *Environment and Behavior*, Vol. 27, pp.723-43
312. Steuer, R.E., Gardiner, L.R. and Gary, J. (1996) 'A bibliographic survey of the activities and international nature of multiple criteria decision making', *Journal of Multi-Criteria Decision Analysis* Vol. 15, No. 3, pp. 195-21

313. Su, J., Xi, B.D., Liu, H.L., Jiang, Y.H. and Warith M.A. (2008) 'An inexact multi-objective dynamic model and its application in China for the management of municipal solid waste', *Waste Management, Vol. 28, No.12*, pp: 2532-2541
314. Sudhir,V., Muraleedharan, V. R. and Srinivasan, G. (1996) 'Integrated Solid Waste Management in Urban India: A Critical Operational Research Framework', *Socio-Econ. Plann. Sci.* Vol. 30, No. 3, pp. 163-181
315. Tanaka, M., Kaneko, N., Takahara, N. and Shekdar, A.V. (2004) 'Sustainable health care waste management in Japan', Presented paper in ISWA World Congress, 17–21 October 2004, Rome, Italy.
316. Tanskanen, J. H. and Melanen, M. (1999) 'Modeling separation strategies of municipal solid waste in Finland', *Waste Management and Research*, Vol. 17, pp. 80–92
317. Tanskanen, J.H. (2000) 'Strategic planning of municipal solid waste management', *Resources, Conservation and Recycling*, Vol. 30, pp. 111–133
318. Takagi, H. and Hayashi, I. (1991) 'NN-driven fuzzy reasoning', *International Journal of Approximate Reasoning*, Vol.5, pp.191-212
319. Tchobanoglous, G., Theisen, H., and Vigil, S.A., (1993). '*Integrated Solid Waste Management Engineering Principles and Management Issues*', McGraw Hill, New York
320. TERI (2001). Tata Energy Research Institute. '*State of Environment Report for Delhi*' New Delhi
321. TERI (2002). Tata Energy Research Institute. 'Performance Measurements of Pilot Cities', Tata Energy Research Institute, New Delhi, India.
322. Tesfamariam, S. and Sadiq, R. (2006) 'Risk-based environmental decision-making using fuzzy analytic hierarchy process', *Stochastic Environmental Research and Risk Assessment*, Vol. 21, No. 1, pp. 35-50.
323. Thomas, B., Tamblyn, D. and Baetz B. (1990) 'Expert systems in municipal solid waste management planning', *Journal of Urban Planning and Development* Vol. 116, No.3, pp. 150-155.
324. Tin, A. M., Wise, L.D., Su, W-H., Reutergardh, L. and Lee, S-K. (1995) 'Cost-benefit analysis of the municipal solid waste collection system in Yangon, Myanmar', *Resources, Conservation and Recycling*, Vol. 14, pp. 103-131.
325. Tonglet, M., Phillips, P.S., and Bates. M.P. (2004) 'Determining the drivers for householder pro-environmental behaviour: waste minimization compared to recycling', *Resources, Conservation and Recycling* Vol. 42, pp. 27–48
326. Tonn, B.E. and Peretz, J. H. (2001) 'Method for Gauging Limits to foresight in Environmental Decision Making', *Technological Forecasting and Social Change*, Vol. 67, pp. 35–53
327. Triantaphyllou, E., Kovalerchuk, B., Mann, L. and Knapp, G.M. (1997) 'Determining the most important criteria in maintenance decision making', *Journal Quality Maintenance Engineering*, Vol. 3, No.1, pp.16–24
328. Truitt, M., Liebnman, J., and Kruse, C., (1969)' Simulation model of urban refuse collection', *Journal of the Sanitary Engineering Division*, pp. 289–298
329. Tsakona, M., Anagnostopoulou, E. and Gidarakos, E. (2007) 'Hospital waste management and toxicity evaluation: A case study', *Waste Management*, Vol. 27, pp. 912–920.

330. Tucker P., Grayson J., and Speirs D. (2001) 'Integrated effects of a reduction in collection frequency for a curbside newspaper recycling scheme', *Resource Conservation and Recycling*; Vol. 31, No. 2 pp.149-70
331. Uddameri, V. (2003) 'Using the analytic hierarchy process for selecting an appropriate fate and transport model for risk-based decision-making at hazardous waste sites', *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management* Vol. 7, No.2, pp. 139–146
332. Ulutas, B.H. (2005) 'Determination of the appropriate energy policy for Turkey', *Energy* Vol. 30, pp. 1146–1161
333. United Nations 2008 http://www.un.org/esa/population/ (Last accessed 5th June 2010)
334. UNDP (2005). United Nations Development Program. Human Development Report. Obtained through the internet http://hdr.undp.org/en/reports/ (Last accessed 25th May 2010)
335. UNEP, 2002 www.unep.org (Last accessed 5th June 2010)
336. UNEP-IETC and HIID, (1996) 'International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management', United Nations Environment Programme (UNEP), International Environmental Technology Centre (IETC)
337. US Congress, Office of Technology Assessment (1990) 'Finding the Rx for Managing Medical Wastes', OTA-O-459, Government Printing Office, Washington, DC
338. United States Environment Protection Agency (USEPA) (2002) http://www.epa.gov/ (Last accessed 20th June 2010)
339. Vahidnia, M. H., Alesheikh,A. A. and Alimohammadi, A. (2009) 'Hospital site selection using fuzzy AHP and its derivatives', *Journal of Environmental Management* Vol. 90, pp. 3048–3056
340. van Huylenbroeck, G. (1995) 'The conflict analysis method: bridging the gap between ELECTRE, PROMETHEE and ORESTE', *European Journal of Operational Research* Vol. 82, pp. 490–502
341. Venkateswaran, S. (1994) 'Managing waste: ecological, economic and social dimensions', *Economic and Political Weekly*, Vol. 29, No. 45 & 46, pp 2907
342. Verma, L. K., Mani, S., Sinha, N. and Rana, S. (2008) 'Biomedical waste management in nursing homes and smaller hospitals in Delhi', *Waste Management*, Vol. 28, No. 12, pp. 2723-2734
343. Verma, Sh. (2002) 'Anaerobic Digestion of Biodegradable Organics in Municipal Solid Wastes', Department of Earth and Environmental Engineering, Fu Foundation School of Engineering and Applied Science, Columbia University.
344. Vining, J. and Ebreo, A. (1989) 'An evaluation of the public response to a community recycling education program', *Society and Natural Resources* Vol. 2, pp. 23– 36
345. Vining, J. and Ebreo, A. (1990) 'What makes a recycler? A comparison of recyclers and non-recyclers', *Environment and Behavior*, Vol. 22, pp.55-73
346. Visvanathan, C. and Trankler, J. (2003) 'Municipal Solid Waste Management in Asia: A Comparative Analysis' www. swlf.ait.ac.th (Last accessed 3rd Spetember 2010)
347. Wang, G. H., Wang, Y. X. and Zhao, T. (2008) 'Analysis of interactions among the barriers to energy saving in China', *Energy Policy*, Vol. 36, No. 6, pp. 1879-1889
348. Wang, L.-C., Lee, W.-J., Tsai, P.-J. and Chen, S.J. (2002) 'Potential method for reducing emissions of polycyclic aromatic hydrocarbons from the incineration of biological sludge', *Environmental Science and Technology* Vol. 36, pp. 3420–3425

349. Warfield, J.W. (1974) 'Developing interconnected matrices in structural modelling', *IEEE Transactions on Systems Men and Cybernetics*, Vol. 4, No. 1, pp. 51-81
350. Warmer Bulletin (2000) 'Environmental impacts of transporting waste—life cycle and cost benefit assessments', Warmer Bulletin Vol. 73, pp. 8–10
351. Wedding, G.C., and Brown, D.C. (2007) 'Measuring site-level success in Brownfield redevelopments: a focus on sustainability and green building', *Journal of Environmental Management*, Vol. 85, pp. 483–495
352. Williams, E. (1991) 'College students and recycling: their attitudes and behaviors. *Journal of College Student Development*; Vol. 32, pp. 86-88
353. Whitaker, R. (2007) 'Validation examples of the Analytic Hierarchy Process and Analytic Network Process', *Mathematical and Computer Modelling*, Vol. 46, pp. 840–859
354. Witmer, J. F., and Geller, E. S. (1976) 'Facilitating paper recycling: Effects of prompts, raffles, and contests', *Journal of Applied Behavior Analysis* Vol. 9, pp. 315–322
355. World Bank (1999) 'What a waste: solid waste management in Asia', http://web.mit.edu/urbanupgrading/urbanenvironment/resources/references/pdfs/WhatAWasteAsia.pdf (Last accessed 24th June, 2010).
356. WHO (1999). World Health Organization. 'Safe management of wastes from health-care activities', In: Prues, A., Giroult, E., Rushbrook, P. (Eds.), World Health Organization, Geneva.
357. WHO (2000). World Health Organization. 'Starting health care waste management in medical institutions', *Health Care Waste practical information series 1.*
358. WHO (2001). World Health Organization. 'Review *of health impacts from microbial hazards in health care wastes (Draft)*', Prepared by Salkin, I.F. In: Kennedy, M.E. (Ed.), World Health Organization, Geneva.
359. WHO (2004). World Health Organization. '*Preparation of national health-care waste management plans in sub-Saharan countries: guidance manual*', World Health Organization and the Secretariat of the Basel Convention.
360. WHO (2005). World Health Organization. '*Safe healthcare waste management–Policy paper*' World Health Organization, Waste Management 25, 568–569.
361. WHO (2007). World Health Organization. 'Wastes from Health-care Activities, WHO information, Fact Sheet No. 253', WHO, Geneva, available at: http://www.who.int/mediacentre/factsheets/fs253/en/index.html (25th June 2010)
362. Woolridge, A., Morrissey, A. and Phillips, P.S. (2005) 'The development of strategic and tactical tools, using systems analysis, for waste management in large complex organisations: a case study in UK healthcare waste', *Resources, Conservation and Recycling* Vol. 44, pp.115–137
363. World Bank (2008) http://data.worldbank.org/about/country-classifications (Last accessed on 28th June 2010)
364. World Resources Institute, United Nations Environment Programme, United Nations Development Programme, The World Bank (1996) '*World Resources 1996-97 - The Urban Environment*', Oxford University Press, Oxford.
365. Yang, C.Y., Chen, R.F., Ye, Q.H. and Zeng, D.W. (2002) 'Solve the method of medical waste effectively', *Taiwan Medical Journal* Vol. 45, No.7, pp. 55–56

366. Yang, C., Li Peijun, L., Lupi, C., Yangzhao, S., Diandou, X., Qian, F. and Shasha, F. (2009) 'Sustainable management measures for healthcare waste in China', *Waste Management*, Vol. 29, No.6, pp. 1996–2004.
367. Yedla, S. and Shrestha, R.M. (2003) 'Multi-criteria approach for the selection of alternative options for environmentally sustainable transport system in Delhi', Transportation *Research*, Vol. A No.37, pp. 717–729
368. Yinga, X., Minga, Z. G, Qiua, C. G, Lina, T., Linc, W. K. and You H. D. (2007) 'Combining AHP with GIS in synthetic evaluation of eco-environment quality—a case study of Hunan province, China', *Ecological Modelling,* Vol. 209, pp. 97–109
369. Yong, Z., Gang, X., Guanxing, W., Tao, Z. and Dawei, J. (2009) 'Medical waste management in China: A case study of Nanjing', *Waste Management*, Vol. 29, pp.1376-1382.
370. York, R., Rosa, E. A. and Dietz, T. (2004) 'The ecological footprint intensity of national economies', *Journal of Industrial Ecology*, Vol. 8, pp. 139
371. Yufeng, Z., Na, D., Jihong, L. and Changzhong, X. (2003) 'A new pyrolysis technology and equipment for treatment of municipal household garbage and hospital waste', *Renewable Energy* Vol. 28, pp. 2383–2393
372. Zadeh, L.A. (1965) 'Fuzzy sets', *Information and Control*, Vol. 8, pp. 338-353
373. Zeleny, M. (1982) '*Multiple Criteria Decision Making*', McGraw Hill, New York
374. Zhang, D.Q., Tan,S. K. and Gersberg, R.M. (2010) 'Municipal solid waste management in China: Status, problems and challenges', Journal of Environmental Management Vol. 91, No. 8, pp. 1623-1633
375. Zhang, M., and Zhong, J. (1995) 'Application of AHP in index study of urban environmental planning', *Research of Environmental Sciences*, Vol. 8, No.5, pp. 13-19
376. Ziara, M., Nigim, K., Enshassi, A. and Ayyub, B.M. (2002) 'Strategic implementation of infrastructure priority projects: case study in Palestine', *ASCE Journal of Infrastructure Systems*, Vol. 8, No.1, pp. 2–11
377. Zhu, K. J., Jing, Y., and Chang, D.Y. (1999) 'A discussion on extent analysis method and applications of fuzzy AHP', *European Journal of Operational Research* Vol.116, No.2, pp. 450–456
378. Zopounidis, C. and Doumpos, M. (2002) 'Multicriteria classification and sorting methods: a literature review', *European Journal of Operational Research* Vol.138, pp.229–246.

# APPENDIX

| Abbreviation | Full Form |
|---|---|
| AHP | Analytical Hierarchy Process |
| ANP | Analytic Network Process |
| BANANA | Build absolutely nothing anywhere near anything |
| BMW | Bio Medical Waste |
| CPCB | Central Pollution Control Board |
| CR | Consistency Ratio |
| DCB | Delhi Cantonment Board |
| DEMS | Department of Environmental Management Services |
| DSS | Decision Support System |
| DST | Decision Support Tools |
| e-vector | eigen- vector |
| GNI | Gross National Income |
| GNP | Gross National Product |
| GPS | Global Positioning System |
| HWM | Hospital Waste Management |
| ISWM | Integrated Solid Waste Management |
| LCA | Life Cycle Analysis |
| LULU | Locally unacceptable Land Use |
| MCD | Municipal Corporation of Delhi |
| MCDM | Multi-Criteria Decision Making |
| MIS | Managing Information System |
| MMAA | Ministry of Municipal Affairs & Agriculture |
| MSW | Municipal Solid Waste |
| MSWM | Municipal Solid Waste Management |
| NDMC | New Delhi Municipal Council |
| NGO | Non-Governmental Organization |
| NIMBY | Not in my backyard |
| NOTE | Not over there either |
| O&M | Operation & Maintenance |
| PEB | Pro-Environmental Behavior |
| SWM | Solid Waste Management |
| TFN | Triangular Fuzzy Number |
| UMSW | Urban Municipal Solid Waste |
| UNEP | United Nations Environmental Program |
| USEPA | United States Environmental Protection Agency |
| USWM | Urban Solid Waste Management |
| WHO | World Health Organization |